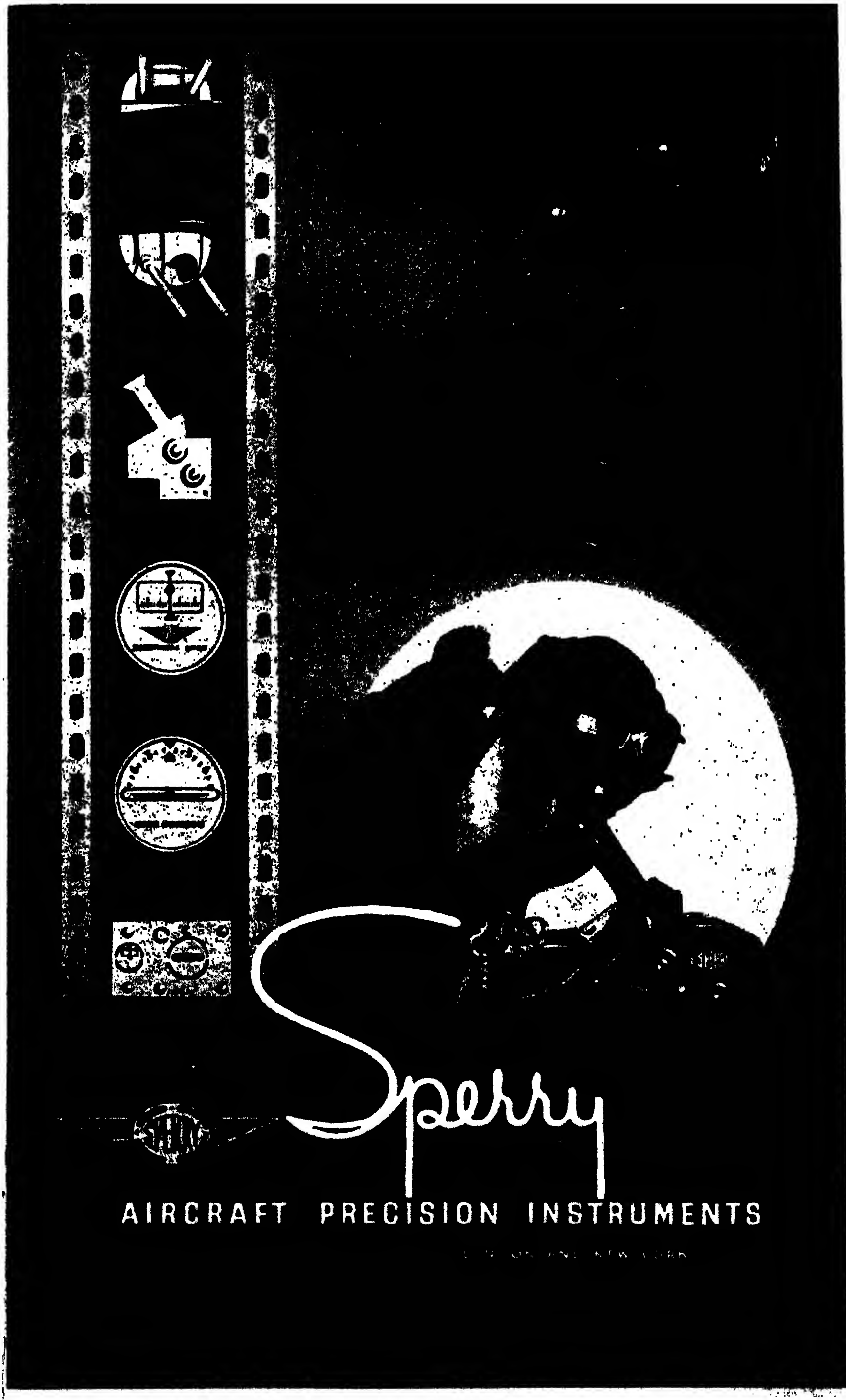
Sperry
AIRCRAFT PRECISION INSTRUMENTS

AEROPLANE PRODUCTION YEAR BOOK AND MANUAL

(I)

Editor:

GROUP CAPTAIN

G. W. WILLIAMSON, O.B.E., M.C.

Member of the Institution of Civil Engineers; Fellow of the Royal Aeronautical Society; Member of the Institution of Mechanical Engineers; Member of the Institution of Electrical Engineers; Assistant Director of Production (Aero-engines), Air Ministry, 1917-18; Director of Production (Contractors' Purchases), Ministry of Aircraft Production, 1940-41

FOREWORD BY

SIR CHARLES BRUCE-GARDNER, M.I.Mech.E.

Chairman, Society of British Aircraft Contractors

PAUL ELEK (PUBLISHERS) LTD.

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FOREWORD

By

SIR CHARLES BRUCE-GARDNER M.I.MECH.E.

Chairman, Society of British Aircraft Constructors.

NOW that the last resources of man and woman power are entering the war factories, future increase of aircraft output must largely come from the more efficient use of labour already in the works. There are many small ways in which productive efficiency can be increased, and I am sure the articles in this book will be most helpful to all those who are interested in aircraft production.

More than in any other engineering industry, the attainment of large quantity production is constantly affected in the aircraft factories by the vital need to maintain the highest possible technical standards, so that our airmen may be provided always with aeroplanes superior in performance and combat qualities to those of the enemy. This means numerous and frequent modifications to meet new needs revealed by battle experience, with inevitable constant deceleration of the productive machine.

Nevertheless, aircraft engineering technique has made great progress during the War, and the Minister of Aircraft Production was able to announce in the spring of this year that output, measured in structure weight produced per productive employee engaged, had increased by some thirty per cent. in the previous twelve months. This is a fine achievement, and it rests upon a basis of experience and knowledge which is the most valuable asset of our industry. Factories and plant can be replaced, but there is no substitute for the " know how."

The Aeroplane Production Yearbook is welcome because it provides a handy means of disseminating knowledge among those who are daily tackling production problems in the factories, and especially to those who have joined the industry in the expansion period. Much of the information contained in the volume was already available in one form or another, but it was scattered in numerous publications and therefore was not in such an easy form to study, which alone makes the *Yearbook* well worth its place on factory reference shelves. It does, in fact, provide much more, and the new matter contained in the volume is equally worth study.

The book is interesting as it reveals something of the many-sided character of modern aircraft engineering. The section on materials touches, for example, on the application of plastics to aircraft construction, a subject of immense potentialities and interest and one in which the technical committees of the Society of British Aircraft Constructors have been particularly active for several years, with most encouraging results. These and other new materials and new methods of working and utilising them are in steady and promising development, offering incalculable possibilities for future use and development—not only for war but for the great future to which we look for aviation in the years of peace.

May, 1943.


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PREFACE

THE purpose of this volume is to provide information in regard to production methods in a compact and accessible form. Books, aircraft periodicals, and manufacturers' technical bulletins pour from the printing presses, but few executives have the time or opportunity to read, extract, and index one-tenth of this flood of information.

On page 447 of this book, an extract from an article in a technical journal points out the expensiveness of neglecting available information, especially where it may result in the completion of a piece of research work of which full records may already appear in up-to-date technical literature. This is not the only risk ; articles of vital importance to production executives may appear in foreign journals, and would not be seen at all if they were not translated and indexed by information bureaux in this country, such as that styled R.T.P.3 in the Ministry of Aircraft Production.

At the back of this book five hundred articles have been listed, and more than one-third prepared in the form of an abstract, as the result of investigations carried out into production literature of the last eighteen months, by courtesy of the staff of R.T.P.3, to whom grateful acknowledgements are made.

The Editor apologises in advance for omissions or errors resulting from war conditions. Some of the most famous names in aircraft production are hardly mentioned ; descriptions of the very latest aircraft are not available, and space and paper have not permitted full description of the production of heavy bombers to be dealt with in this first issue ; these it is hoped to remedy in the next issue.

Despite many wartime difficulties, a book dealing with some aspects of aircraft production has been wrought. If it saves a single hour of the time of a production executive, or provides him with one item of information for which he would have to search, the purchase price will not have been wasted.

Several of the great firms whose products have been described in this volume have referred the Editor to articles which have already appeared in *Aircraft Production*, perhaps the only journal of its kind in the world. The extracts form a compact historical record of the methods of production adopted for some of the aircraft whose names, amongst others, will remain in our memories as long as aircraft fly—Master, Spitfire, Blenheim, Wellington, and Sunderland.

Other articles have been extracted from the pages of *Aircraft Production* with the generous permission of Mr. Geoffrey Smith, M.B.E., the Managing Editor ; any fortunate possessor of the last four bound volumes of *Aircraft Production* need hardly refer to this smaller work, but it is probable that very few executives will be in that happy position. Where they are not, they may like to possess, in this book, a large number of illustrations from the pages of *Aircraft Production*, the blocks of which would otherwise have been destroyed at the end of 1942.

As will be seen from the Table of Contents, the book consists of the following parts : Part I, comprising a series of articles on the fundamentals of aircraft production, including one by Mr. Geoffrey Smith which renders any other forecast of future development unnecessary ; Part II, a summary of methods applicable to particular materials, and dealing also with recent machine tool and small tool developments especially applied to aircraft production ; Part III deals with the manufacture of particular aircraft ; Part IV provides a list of technical articles under headings representing the various divisions of this book, so that any executive may find for himself a considerable range of technical information which could not possibly be fully covered within the confines of a book such as this.

Detailed acknowledgement of the source of articles and illustrations is made at the end of the volume, a procedure which has been agreed with some of the great firms who have so generously provided full details of their processes and products.

The Editor and Publisher would be grateful for suggestions and constructive criticism which may help in improving any subsequent edition of this publication ; without co-operative effort by the firms composing the aircraft industry, no such book could be produced.

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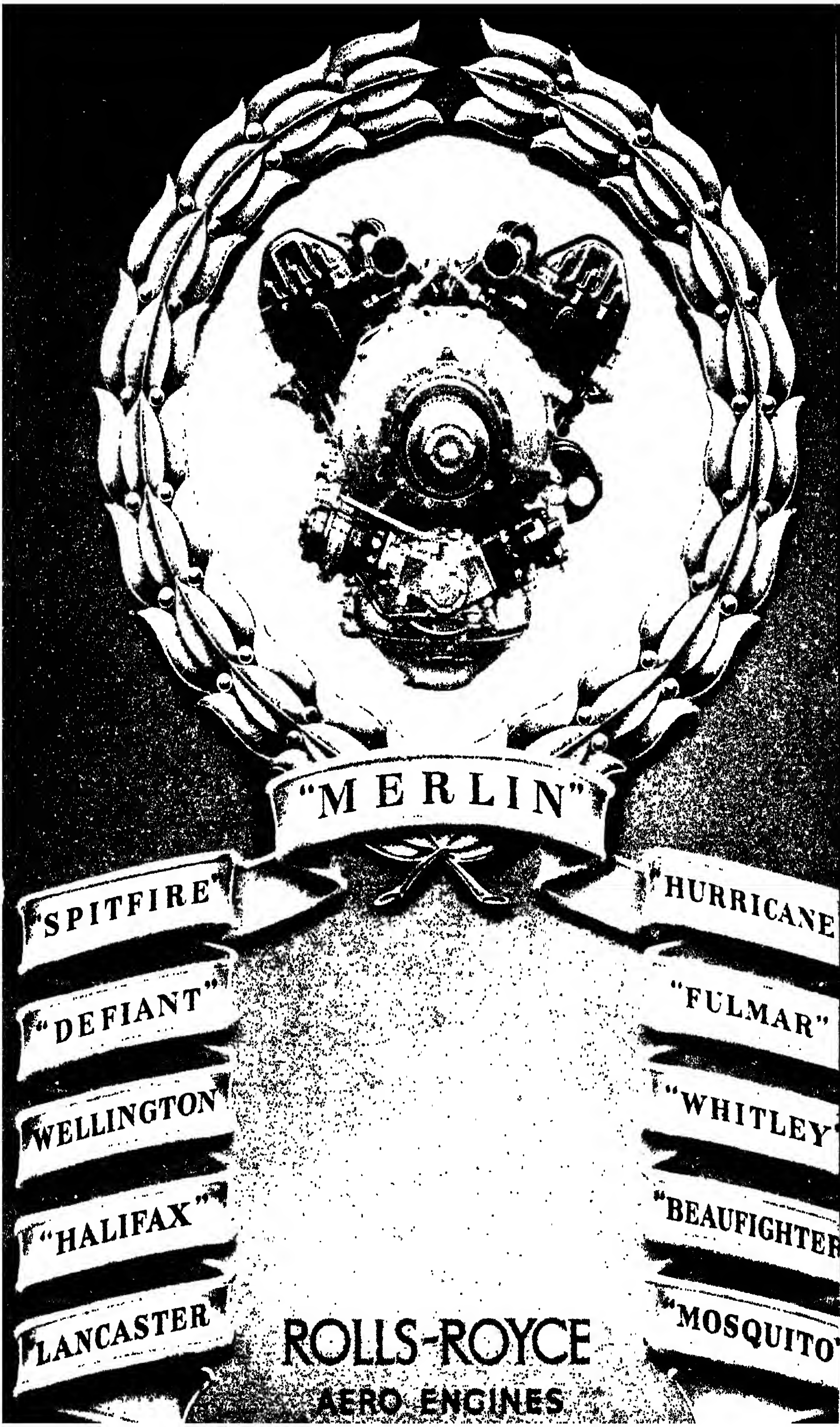
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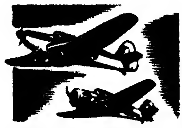

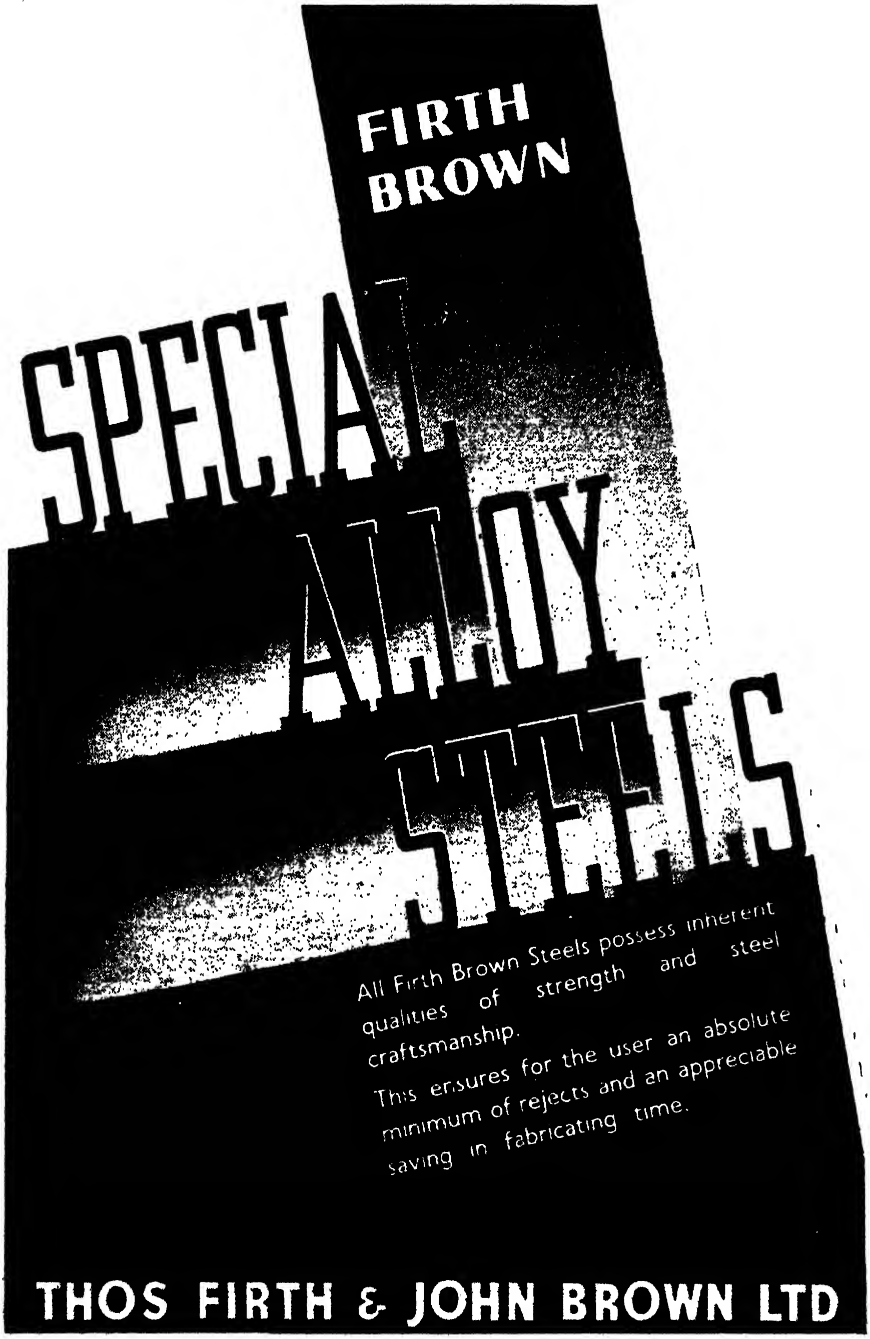
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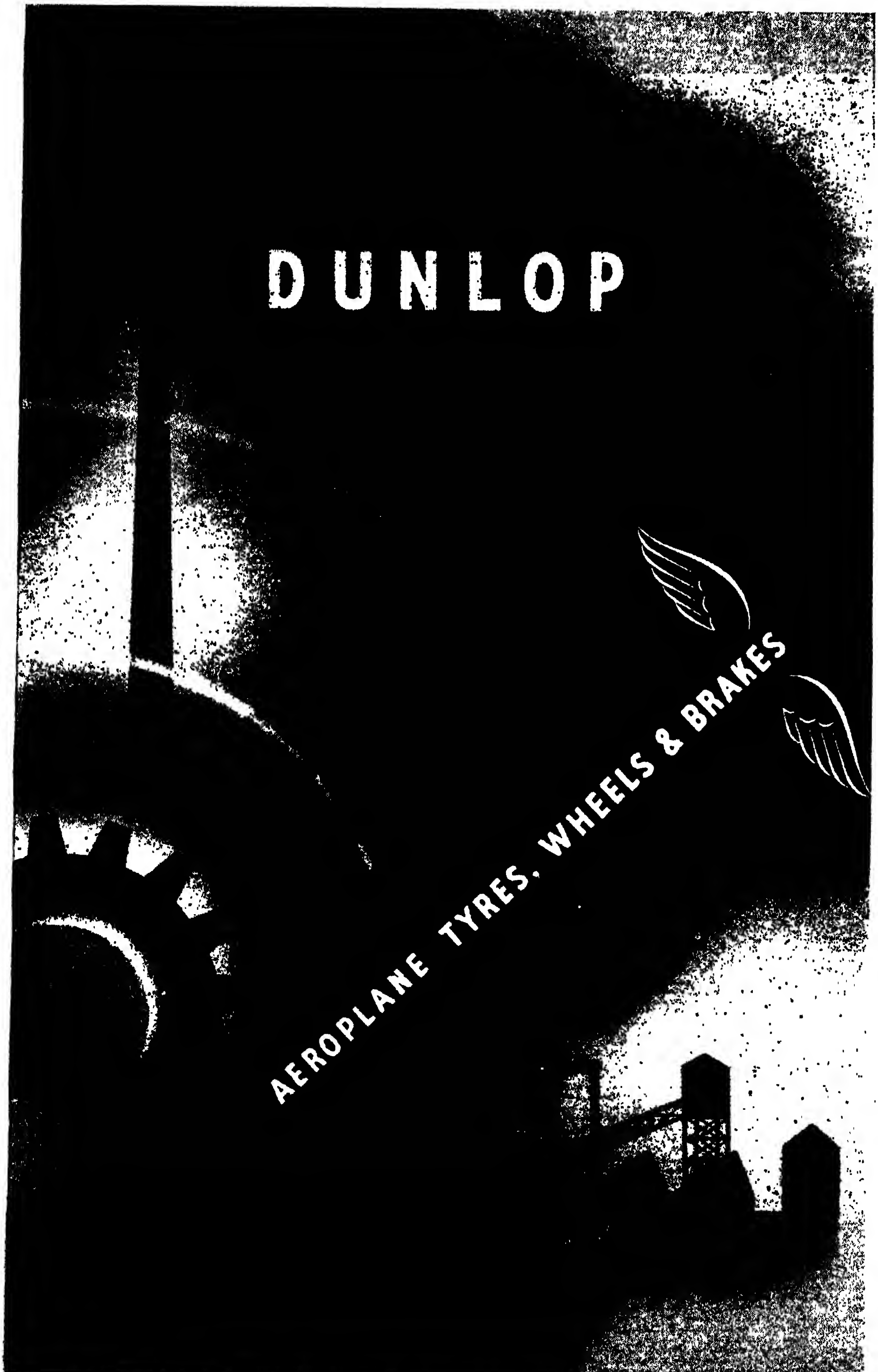
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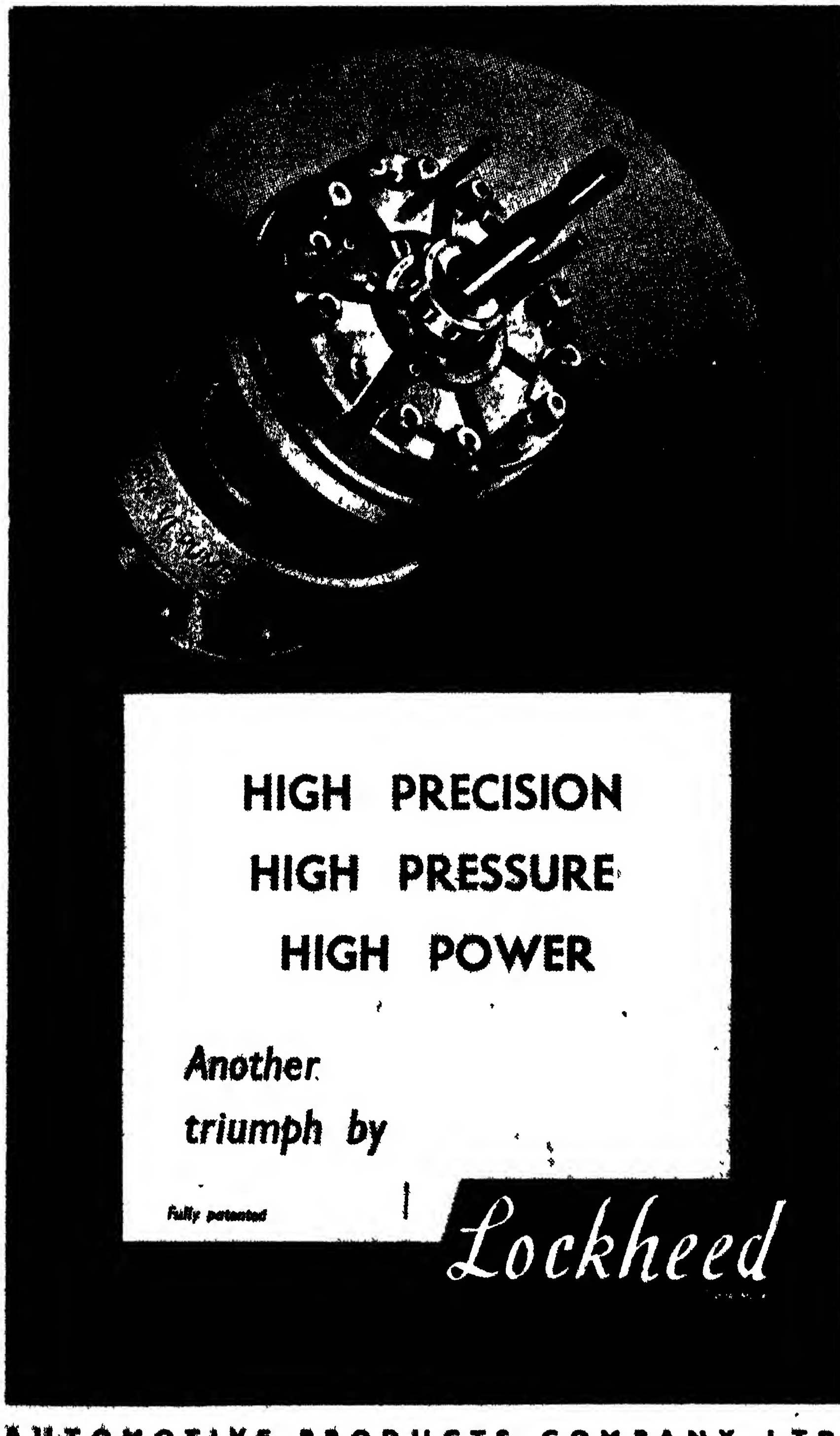
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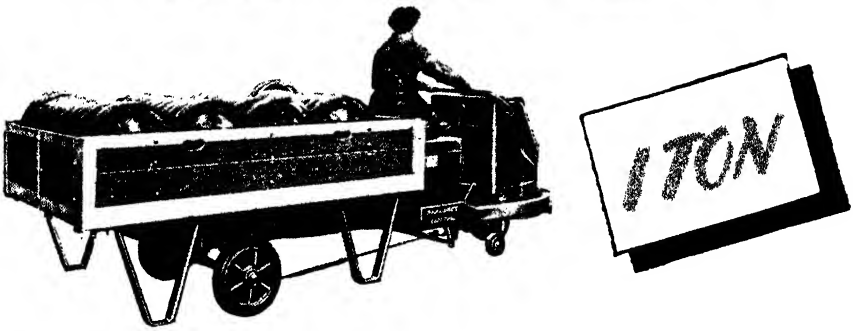

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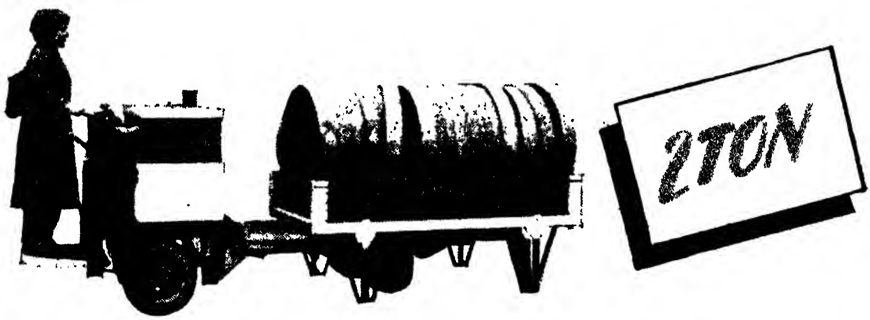

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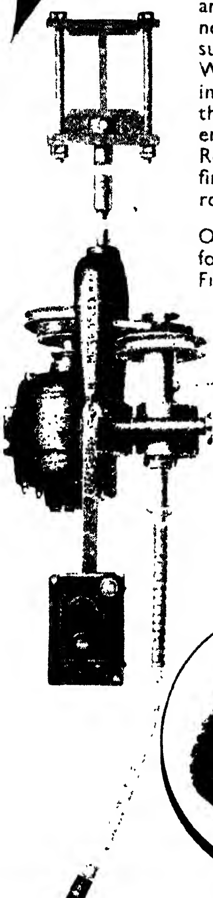

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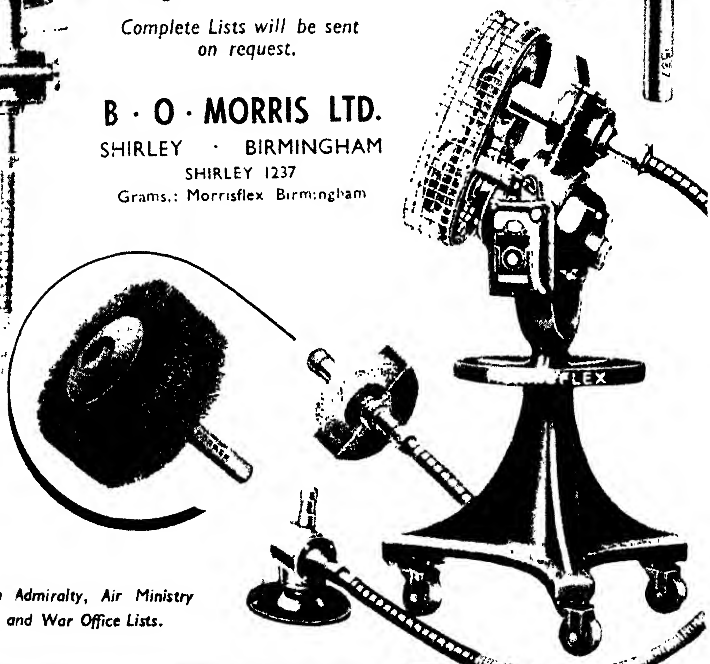

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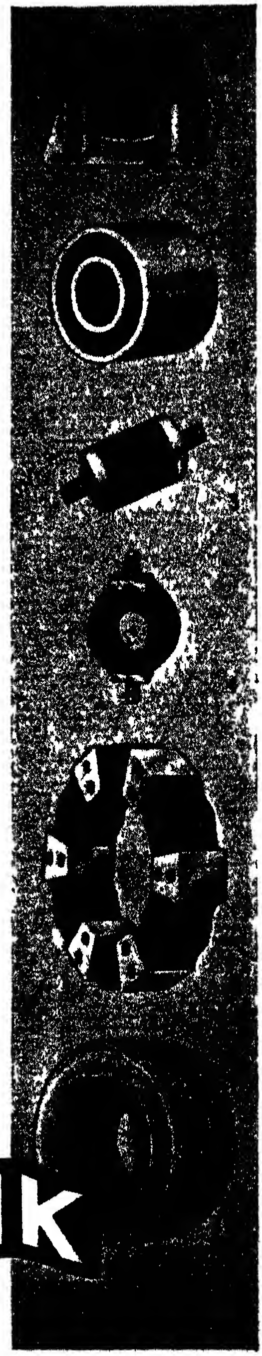

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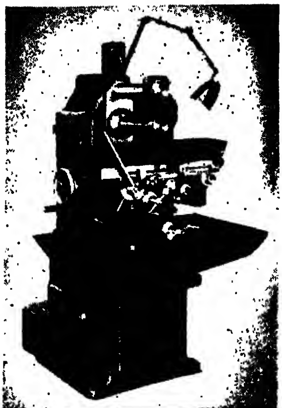

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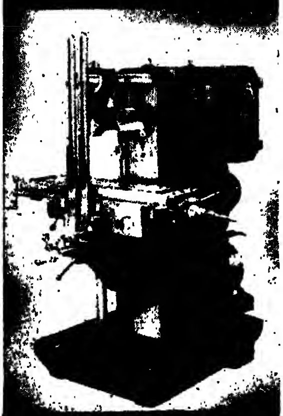

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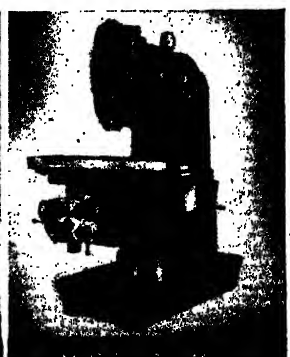

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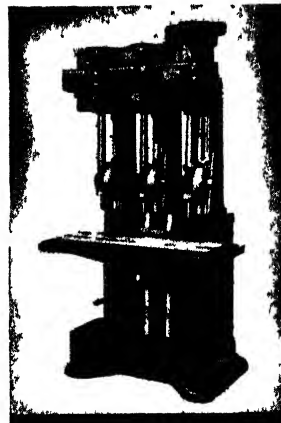

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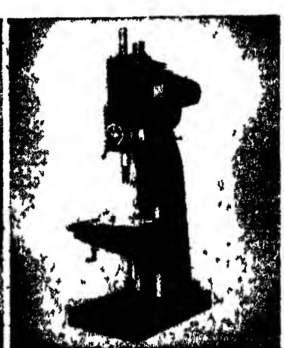
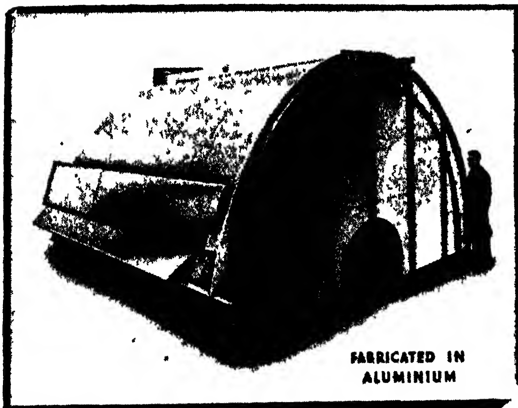


(4) TYPE G MODEL 650

(3) TYPE SH MODEL 6[illegible]



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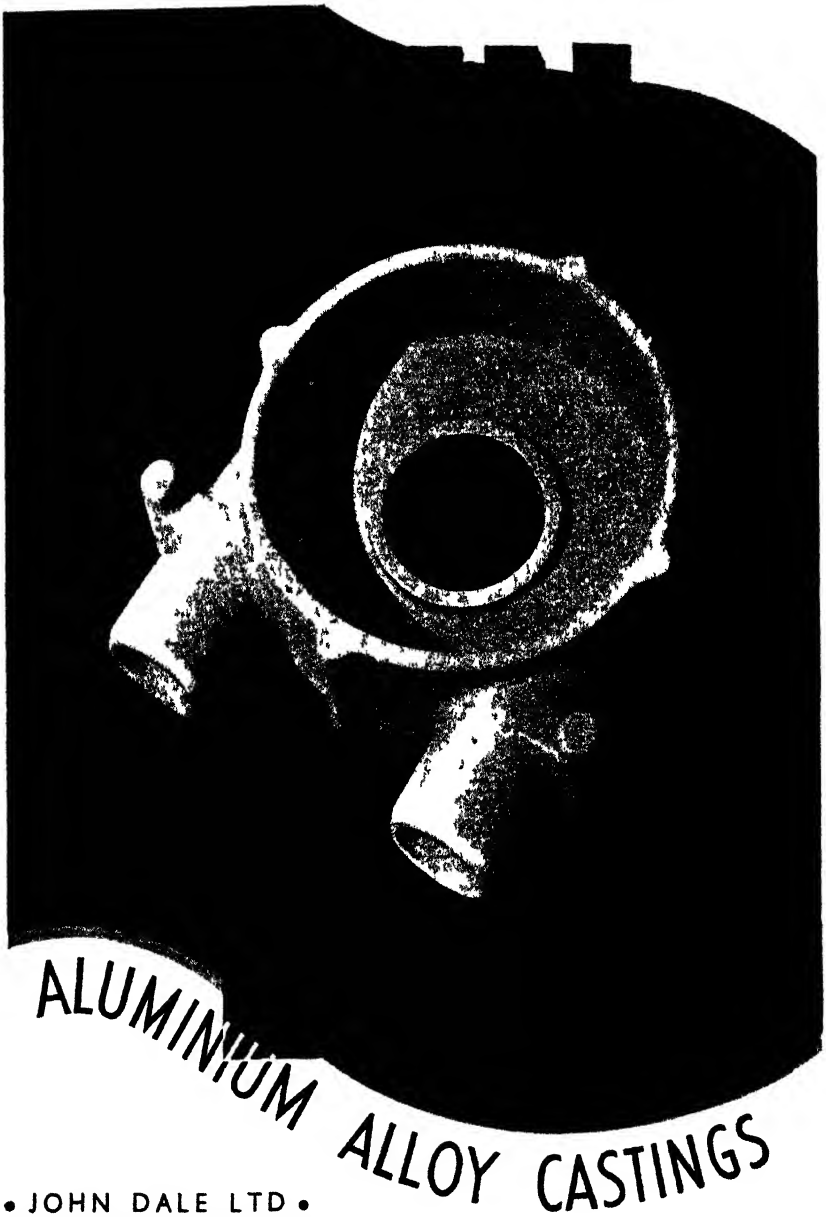
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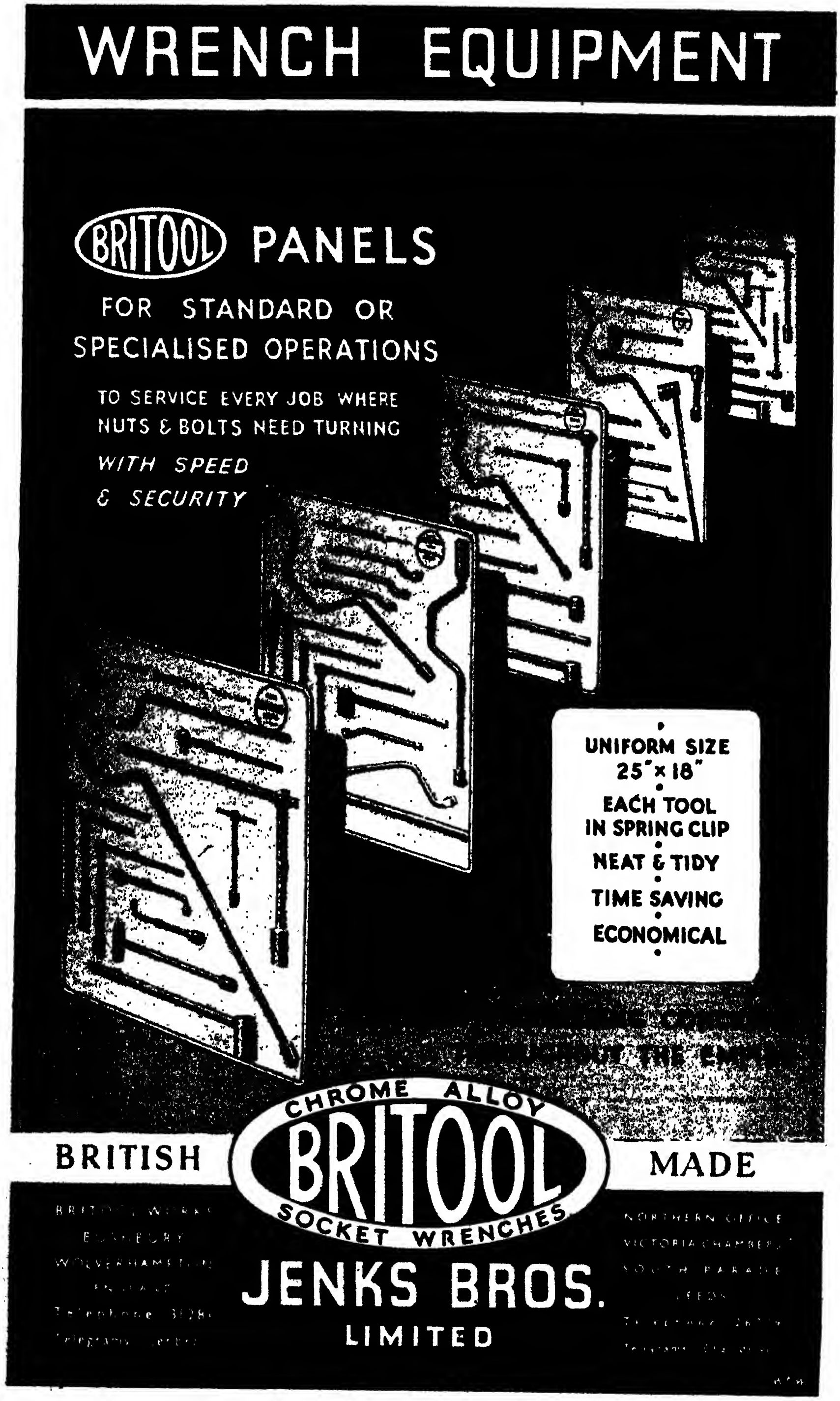
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METAL WORKING AND HEAT TREATMENT YEARBOOK AND MANUAL

Editor: F. JOHNSON, D.Sc.

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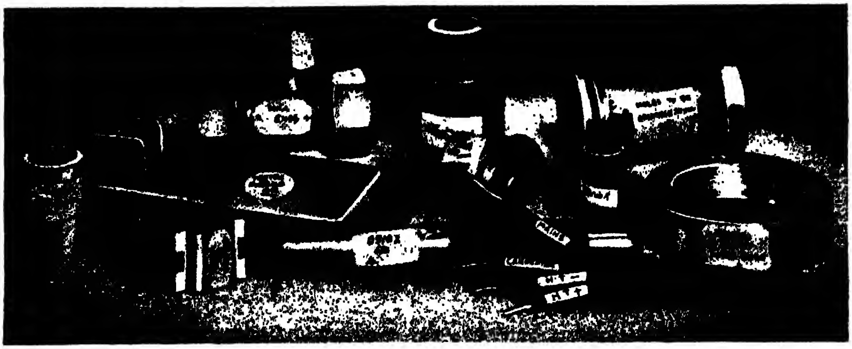

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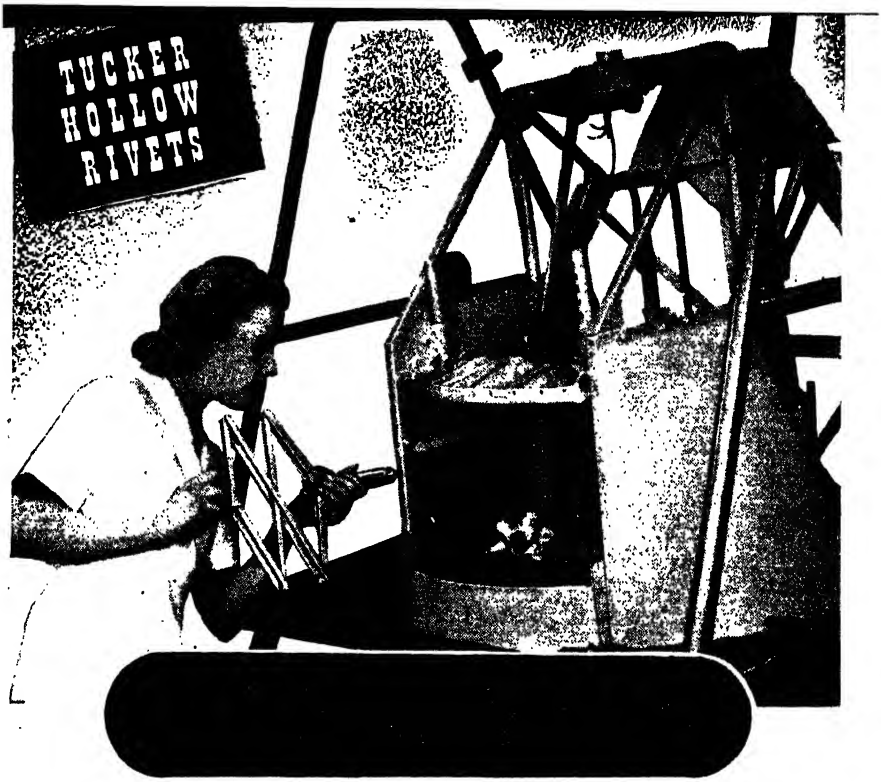
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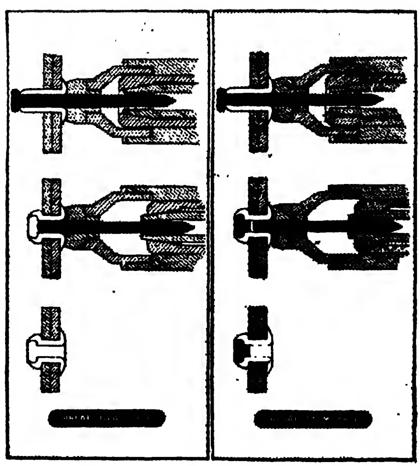

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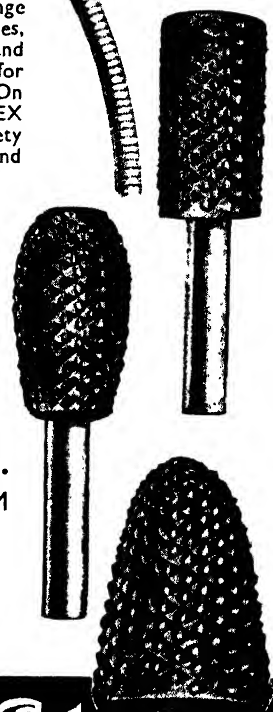

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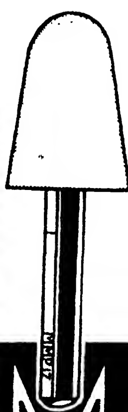

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Part I

PRODUCTION AFTER THE WAR
The Transition Stage from War to Peace

By G. GEOFFREY SMITH, M.B.E.

(Managing Editor of "*Aircraft Production*")

Commerce is the Lifeblood of Civilisation

THE transition of the now immensely expanded aircraft industry from a wartime to a peacetime basis will be a vitally important period in its history. Vital indeed to our future national prosperity. Peace may come suddenly and British industry must be ready for it with carefully planned ideas of procedure. The haphazard improvisation of 1919 onwards, the lapsing of a big aircraft industry built up after many years of toil, are repugnant to all and particularly to the mind of the engineer. One thing is certain, and the fact finds few dissentients : the entire world will be changed, but exactly how it is impossible to forecast. On what system commerce will be conducted is uncertain and most problematic. Whether nations will resort to fierce competition or work in a collaborative spirit for the good of mankind cannot be foretold. Commerce is the lifeblood of civilisation. Into this post-war arena a new international air transport system of immense importance to the future well-being of the world at large is being moulded.

It would be a bold man who would attempt to dogmatise upon the future of an industry so young, so virile and yet so transcending in its potentialities.

After the war, the demand for new aircraft for passenger transport and certain classes of freight and the services they fulfil, will undoubtedly be conditioned by the sort of world in which nations find themselves.

Reciprocal Benefit between Nations

Air transport promises to revolutionise travel. Britain's position and influence in world affairs and those of the British Commonwealth of Nations will be largely determined by statesmanlike solution of the many problems which the new era of rapid world-wide transport will introduce.

Thus our aircraft technicians, jointly with those members of the Government who are responsible for framing and issuing a guiding policy, hold the keys to a solution of these new problems with which are bound up our future national security and economic prosperity. Present indications do not suggest that intense international competition will be lacking in the field of post-war air transport, but the hope is that when we have emerged from world conflict, nations will not return to a highly competitive state, but instead reach agreement by a reciprocal arrangement of benefit to all. Development of aircraft can bestow enormous blessings upon the world, yet it can be utilised as a lethal weapon of devastating horror, as we have seen. Civil aviation, it has been said, must " fly by itself " and it is far better that it should, but on equal terms. Government subsidies may take many forms, and result in unfair competition. Now is the time for plans to be worked out which will ensure that aircraft manufacturers in this country have a fair chance of establishing world airlines and regular air communications with every part of the British Commonwealth and of building the specialised aircraft which can make this possible. This can only be done after Government consultation with the Dominions concerned and by international agreement as to spheres of influence.

World Air Routes and Feeders

Meanwhile, major questions require serious study and answer so far as our own manufacturing resources are concerned. Firstly, considering air-lines particularly, there will presumably be at least two major sections : one to operate world air routes by mammoth air liners approximately 100 tons all-up weight and multi-engines developing over 15,000 h.p. with every passenger comfort for long-distance travel. The other as " feeder " lines to serve the needs of internal communications both here and in Possessions abroad. Conditions in this sphere would imply much smaller aircraft with perhaps two or, may be, four engines.

Operation by Railway and Shipping Companies

There are already definite indications that in the post-war era shipping companies will operate long-distance air-lines, and it is highly probable that railway companies will take a hand in the running of feeder or internal network of air services, which might also extend to European capitals.

Interim Conversion of Bombers

When peace comes, it is inevitable that there will be in existence many large aircraft, primarily designed for war purposes, but capable of being adapted reasonably quickly for either passenger or goods transport. Such transformations have, indeed, already been envisaged. Large bombers might well be adapted to carry long-distance air mails, which service would no doubt appeal to many R.A.F. pilots as a necessary and desirable Government service. Wartime aircraft, nevertheless, cannot be regarded as ideal for either passenger or freight carrying, though they may form a valuable temporary stop-gap. It is to be hoped that this period will be of the shortest possible duration—in fact, it would be better avoided altogether—as signs are not lacking that modern types designed for passenger airline operation will be at once available from the other side of the Atlantic.

Whether the largest types, when evolved, will be flying boats or landplanes cannot be accurately forecast at this stage, most probably both will find a place. Prior to the war, the tendency was to employ landplanes for high-speed mail and passenger traffic with seaplanes for cargo and freight-carrying purposes generally.

Concentration into Large Factories

The machines, however, will almost assuredly be so big that one cannot envisage a landplane being produced by any factory lacking a sufficiently large airfield immediately adjoining. Huge flying boats, too, would naturally involve manufacturing plants of sufficient capacity adjoining natural resources for all-the-year-round test-flying. By this is implied that the method of scattering parent works and component factories and assembling large aircraft in a central works and then laboriously towing them for many miles to a suitable airfield cannot be tolerated after the war. For one thing the dimensions of the newer aircraft would hardly permit such a practice. Greater efficiency then will be attained by concentration. This practice, if adopted, would automatically rule out some factories for the manufacture of large transport aircraft of the future.

Selection of Plants for Retention

This question of manufacturing facilities is of importance in another connection. Many aircraft factories on the largest scale have been erected under the Government Shadow Scheme, and it would be a grave error if for any reason these plants, which in most cases are models in their layout and equipment, should be lost to the aircraft industry in the difficult years of the post-war period. Most of the " parent " factories of the long-established aircraft companies have grown with the development of aviation and reflect, in their piecemeal layout and original lack of big-scale planning, the vicissitudes through which the industry has passed.

The selection then of the more desirable plants to maintain for aircraft production in peacetime will require careful study, hand in hand with the process of scaling down and redistributing production facilities and personnel. At the end of the Great War of 1914–1918 the output of aircraft had reached 3,500 per month. In those far-off days aircraft were mainly biplanes of spruce and canvas, and simple in their specifications. A far greater effort has been needed in this war to produce a smaller number of machines involving incomparably more difficult manufacturing technique by reason of the change to all-metal construction, larger types, and greater structural complexities. Equipment and accessories for aircraft to-day is a large industry in itself.

Works Production Councils

The experiment of running a business and controlling and expanding production by means of joint committees of labour and management, may in the future, eventually emerge triumphant over all other forms of joint endeavour, inducement, and spur to effort, despite payment by results, but no management or committee can succeed if it lacks energetic leadership and inspiration. That is ever true of industrial undertakings, great and small. It is thus apparent that during the difficult early post-war years, many complex inter-related problems concerning personnel and policy will require solution.

Apprenticeship Again

One of the first of these problems will be that of the steady release of the very large percentage of dilutees and female labour to make way for the absorption of former peacetime engineering employees now serving with the Forces and desiring to return. Also the apprenticeship system, which was largely allowed to decline throughout the inter-war years from 1918 onwards, should be re-established. The decay of this system in all but a few aircraft factories has been responsible in some measure for many of the difficulties encountered in the speeding-up of production in the present conflict. The lack of sufficient properly trained engineering personnel was a great drawback when the expansion scheme was envisaged. On the outbreak of hostilities, with the calling-up of large reserves of skilled and semi-skilled man-power from engineering factories, the reservoir of personnel available for the training of dilutees and woman labour was reduced to a far too dangerous level. This lesson, learned but not heeded after the last war, must dominate works policy in the years ahead if British engineering prestige is to retain its predominant place in the post-war world.

Restoration of Individual Enterprise

It is important to realise also, that in the transition from a war to a peace basis, much of the present co-ordinated production technique must lapse. The industry, gradually reduced in size and personnel, will change over from common co-operation in a national effort to individual enterprise and normal inter-factory rivalry for the business and markets of the post-war world. Whether international co-operation or intensified competition be the keynote of post-war aviation, we shall need the best manufacturing facilities at our disposal to translate speedily into reality the aircraft now being visualised by our designers.

Design and Individuality

On the score of design itself we need feel no apprehension. In every branch of aeronautics our designers have convincingly demonstrated their ability to look ahead and to evolve to-day the aircraft that will be needed to-morrow. There is no reason to suppose that the foresight and inspiration which have given to the Royal Air Force aircraft yet to be equalled by ally or foe alike, will be lacking for the less strenuous, but no less exacting, requirements of commercial aviation. At present the imperative need for quantity production overrides the individual element so characteristic of the British. Individualism has been in the past the vital dynamic force that added great lustre to the name of Britain. In the aircraft world it has indeed given us that superiority in quality which is now being translated into a like pre-eminence in quantity. Individuality and initiative must be continued and encouraged.

A National University of Aeronautics

The importance the British aircraft industry has assumed and the influence that aerodynamics and modern production methods will exert upon the future of the world, warrant the establishment and Government endowment of a central national University of Aeronautics. By this means the aircraft industry could attain a pre-eminence in its own sphere of engineering comparable with that of Oxford and Cambridge in general learning and others which might be named in specialised subjects.

New Technique

One development may be regarded as certain : aircraft construction will be radically changed. Many of the difficulties associated with large-scale manufacture have been due to the fact that it became necessary during an interim or adolescent period when aircraft were in the " bits-and-pieces " stage characteristic of all young industries. Sooner or later a combination of circumstances enforces stabilisation and simplification of design. That stage has not yet been reached to any marked degree in aircraft design and it may be some years before it is attained. The present period is still largely concerned with the gaining of knowledge and the development of new materials which will certainly come increasingly into use. Ultimately, however, this mass of knowledge will be correlated, absorbed and crystallised into new techniques of manufacture suited to the circumstances and requirements of operational conditions. This does not, of course, imply that development will cease, but that it will be canalised and directed to the attainment of future requirements rather than to some extent dictating the pace of advancement.

Plastic Development

Both here and in America intensive research and experiment are proceeding in the use of plastics and allied structural materials such as improved woods. Even now it is not merely an inventor's dream that some types of light aircraft may be manufactured almost entirely by moulding processes. Such aircraft may well appear in the form of a light two-four seater type of what may be termed the private or owner-driver variety. Indeed, with a clear-cut Government policy governing privately owned aircraft, this simpler type may conceivably be the one to make most headway in the immediate post-war period, though it may be doubted whether " owner-flying " will ever attain the proportions of popular motoring as is frequently suggested. There are fundamental differences in operating conditions.

Planning for Production

Turning once more to the immediate future, the story of the enormous difficulties of the aircraft production front in the early days of the present conflict bears indisputable witness to the failure to plot machines for easy production, and interchangeability by standardisation of component parts. No one works department should be left to design aircraft for production : far better a small cadre or cell of the best brains from all works engineering departments to collaborate, study and plan each component from the different points of view of the production chiefs of the machining, assembly and maintenance departments. Constructive criticism at every stage is essential before a design is finally passed for production, as so much depends upon the early stages if constant delays due to modifications are to be avoided. The creation of any new type is still a four years' job. Manufacturer, purchaser and operator benefit alike by collaboration, for planned and coherent production spells low factory costs, and results in ready servicing, to the benefit of users at home and abroad.

Workshop production methods and the specialised tools employed have improved out of all knowledge during the war. One reason for the progress attained in general production technique is the large-scale orders to which our factories have now become accustomed. Planning on efficient lines can best be achieved on repetition work. New machine tools, improved materials and their treatment have reduced by thousands of man-hours the production of given types. Coupled with mechanised and flow production technique a fighter type to-day may take under 10,000 hours as compared to over 20,000 in 1939 ; a four-engined bomber 40,000 hours or an appreciably shorter time than even a two-engined bomber four years ago. All this indicates the remarkable state of efficiency attained by British industry and the readiness to adopt new ideas in planning and production so soon as large-scale orders merited heavy outlay on the most modern plant.

A Strengthened Industry

Thus the British aircraft industry, with its wartime personnel estimated to number a million, will embark upon its peacetime programme with a wealth of experience and strength to guide it. Not only have aircraft engineers of long standing specialised in the work, but many famous automobile engineers have contributed fresh views and valuable experience to the great task so magnificently performed in the aircraft and engine workshops. In the evolution of power units British experience is second to none as proved by results, whilst research and development work on future types of aircraft and power units are the envy of the world.

Improved Power Plants

It is often overlooked that for commercial aircraft, which must operate economically, modified types of engines of greater horse-power and reduced fuel consumption will be an urgent need. Operational costs assume a new importance. Diesel engines may reappear for long-range types. One is apt to overlook the economy aspect in wartime when speed and power are the all-important considerations. From 2,500 h.p. we may need to step up towards units of 5,000 h.p., which implies multi-bank air-cooled radials and liquid-cooled units of X and H formation with twenty-four or more cylinders. We may indeed derive power as the result of an entirely new field of development. The gas turbine has made considerable headway of late years, and its appeal will become the more important as bigger sizes are demanded and the vast experience of manufacturers of large turbo-compressors takes the aircraft engineer proper out of the more experimental field. Turbines may conceivably be used in conjunction with contra-

rotating airscrews, the exhaust efflux of the turbine being utilised as an auxiliary means of jet propulsion. In airscrew design we already produce efficient examples of every type with from two to six blades, the latter, of course, of the counter-rotating type.

Need for a Policy Now

Pressure cabins for stratosphere flight are an important immediate problem for research. Many believe that long-distance transport air-liners will operate in the upper stratosphere, where ice formations do not exist and the atmosphere is little disturbed by storms. Production engineers and technicians thus have an abundance of major problems to solve, yet, most regrettably, just as they cannot complete the design of suitable air transport until operators define their requirements, such as the standard of comfort desired, non-stop range, maximum and cruising speed, pay-load, take-off and rate of climb, so operators are prevented from formulating their plans until Government air policy has been clearly defined and studied.

THE MINISTRY OF AIRCRAFT PRODUCTION

By S. R. CAUTHERY, O.B.E.

(*Assistant Deputy Controller of Production*, 1942)

USUALLY, when you ask the chief of a factory working for a Government Department just how that Department's services are being used to help him, he will look at you —in pretty much the same way as Job probably looked at his friends when telling them that, after all, they were the people and wisdom would die with them—and say: "The only way any Government Department can help me is to leave me alone, and if that had been done in the first place I might have got somewhere."

Aircraft constructors are probably no exception. Beset always by various Ministries, all apparently collaborating to impose restrictions that create difficulties in planning and policy; besieged by official callers trying to enforce such impositions; bestrewn with official documents relating to one phase or another of factory operation or administration, the aircraft manufacturer tends to brand everyone and everything emanating from a Ministry as a nuisance, and to overlook the many services rendered him by his own Ministry of Aircraft Production.

Reduction of Interference by Other Ministries

For M.A.P. most emphatically does help the designer-constructor in no small degree. Indeed the help which the Government gives lies chiefly in the fact that whatever contractors may say to the contrary, interference is reduced to a minimum. It must not be forgotten that the creation of the Ministry of Aircraft Production was a measure designed to speed up output in the industry in war-time. Therefore, although the exigencies of war itself must dictate the rapidity with which machines are got into the air, it is M.A.P. which has to administer the means of maintaining the stream of output.

Prototype Orders

One bottleneck, for instance, which was removed at the outset was the abolition of the principle of building aircraft after a prototype was finally approved. In the old days it used to take up to a couple of years to perfect a prototype. If then it failed in its projected mission another had to be worked out. Not much imagination is called for in considering the effect of this system on output. By the time even that a contract was placed the prototype was out of date. To-day, as the prototype is constructed, the first few dozen aircraft of that type are produced concurrently. One prototype is turned over immediately to the Air Ministry for operational testing. The other remains at the aeroplane plant for production purposes.

Modifications

Obviously this principle scales down to an appreciable extent the designer's worst headache—the question of " mods." The majority of modifications of course become necessary after actual battle conditions have been experienced. But dozens of " mods." may have to be incorporated in the first deliveries. For this purpose, the services of M.A.P. in effecting liaison between the contractor's shops and the Air Ministry technical laboratories are incalculable.

The "mod." sheet for, say, a heavy bomber of a type in wide use, such as the Halifax, is an impressive document. " Mods." are so numerous they have to be classified under priority numbers. It is M.A.P.s job to keep these priorities up to date according to squadron reports as given to the Air Ministry. Half-a-dozen independent reports from squadrons are enough to get a " mod." added to the monthly sheet. Every report is noted. The first one, or two, it is considered, may be attributable to the vagaries of a pernickety pilot or critical crew-member, and these reports remain for a time at the " noted " stage. But if six or more come in from different squadrons, the Air Ministry and M.A.P. get busy at once.

Broadly speaking, modifications come into the two categories " major " and " minor." Several minor " mods." can often be introduced on the line without greatly disturbing the production tempo. But a major " mod." may be dictated by a change in Air Ministry policy, and a certain number of aircraft of a standard accepted type called for which need a special fitting. This may temporarily demand a new schedule, with a reduction in output of the " standard " type. Suppose, for instance, it becomes necessary to supply a number of Lancaster squadrons, detailed for a specific operation with an aircraft fitted with a special type of gun. The total number of machines on the full Lancaster programme is X aircraft per week, and Y per week have to be fitted with the new " mod." A second production line is started at the stage where the " mod." goes on. From that stage X - Y aircraft per week of the standard type are produced, and the Y per week of the modified type are run concurrently, so the total schedule remains constant. M.A.P. has to see that the design and materials for the " mod." are ready at the incorporation stage.

Interchangeability

The system falls down, however, if the factory cannot effect a high percentage of interchangeability. In a certain famous heavy-bomber plant the jigs are actually 85% interchangeable. This is a remarkable achievement in view of the fact that the bigger the aircraft the more jigs are necessary, since the assemblies are built in a number of sections and the programme is a high one. Furthermore, the machine demands a great number of " mods." Not all manufacturers, unfortunately, can claim such a high degree of interchangeability. Some believe they could increase theirs if standardisation of certain assemblies were possible. But the fact that 85% interchangeability can be achieved without it speaks for itself. Here is one very important item in the duties of the A.I.D. inspector : the " master reference case," a kind of jig prototype, is held by the A.I.D. officer in residence.

Inspection

The work of the A.I.D. inspector cannot be too highly appraised. In general, the low percentage of faulty deliveries alone will bear testimony to that. In other war industries where there does not exist a parallel to A.I.D., the number of " casualties " at the stage of physical testing and even at the stage of actual operations shows that branch of the aircraft industry's work in a very good light. How good it has always been, and how high a quality of craftmanship has been engendered in this industry itself, as the result of working to A.I.D. standards, is evidenced further by the fact that many aircraft assemblies are accepted to-day on factory inspectors' O.K. alone. Main essentials, such as engines, hydraulics, controls, etc., require a double check, one by the factory inspector and one by A.I.D. But A.I.D. have saved the industry a great deal of man-hours by delegating inspection of other components to the factory authorities *per se.*

Resident Technical Officers

Among the other resident officials at the aeroplane factory, two of the most useful to the constructor are the R.T.O. and D.A.P. representatives. The duties of both are are too numerous and varied to permit of detailed description here. The R.T.O., for instance is the first officer to be notified officially of any change of design when this

has been approved, and it is up to him to issue and circulate the necessary documents to every department concerned. Until recently he also had to sign every drawing as it was issued from the D.I.S. (Drawing Office Instruction Sheet) list. It is now necessary for the master-sheet only to have the R.T.O.s signature, but when it is remembered that this obligates him to pursue every modification in addition to every primary design, some appreciation of the volume of work passing through R.T.O.'s hands on this count alone can be arrived at.

Resident Representative of Director of Aircraft Production

The resident D.A.P. officer's duties—or rather the capacity expected of him—are practically unlimited. As a liaison officer his services are constantly called in from the design stage onwards. In many factories the D.A.P. officer is one who, before M.A.P. was set up, had had several years' service with the Air Ministry—often in a technical capacity—and in these cases particularly the experience at his command is invaluable to the constructor.

Sub-contracts Branch

Another important service rendered to the aircraft designer is that effected through M.A.P. Sub-contracts branch. When a design has been approved and a programme laid down, the Sub-contracts branch sets to work to find capacity for certain sub-assemblies, manufacture of components, etc. As the programme expands so additional capacity has to be found. Where groups of constructors are involved, as in the case of Lancaster production, for example, the work of the branch is still more complicated, since sub-contract production has to be made to synchronise with that of maybe four or five main contractors.

Instruction of Aircraft Crews

There is one more service of great value to aircraft designers, and likewise to operating pilots and crews. This might be described as an educative service, for it covers the necessity to acquaint and familiarise R.A.F. men on active service with the technical aspects of aircraft they are flying. This technical information, embracing every aspect of construction, is imparted fully and discussed freely at all stages of an airman's training. As a result, practical experience in his aircraft is very much more smoothly acquired and its lessons assimilated, because he knows what to look for and expect in performance and capacity.

This instructional service takes several forms. It begins in the Research Technical Publications section of M.A.P., where a handbook describing in detail every aircraft in service is produced. A separate handbook, issued in two sections, is prepared for each type individually. Volume I deals with Production, Volume II with Repairs. Every aspect is dealt with thoroughly; illustrations and drawings to scale are liberal. Copies are delivered to the individual constructor in each case, and copies of all are issued to the C.O. of each squadron. In some cases the aircraft designer will go a stage further and produce a special publication of his own, but this must not prejudice the production of the handbook written specially to R.A.F. requirements.

Whatever guidance and information the airman has absorbed from this source is broadened and strengthened with practical advice from the test-pilot's summary of findings—also made available to airman and designer alike. It is often known as the "Do-and-Don't" Book, for the test-pilot's observations are usually epitomised in a brief, succinctly-worded list of tips in the Do-this and Don't-do-that form—with equally terse warnings about the consequences of failing to comply.

Pilots and crew-members may visit the factories making the machines they are accustomed to handling—another service benefiting both designer and airman. Not only does it give the aviator added interest in his aircraft, but confidence also in so far as he can see the quality of workmanship that is going into his aircraft and the efforts made by workers to keep him equipped. How much good is done by these visits was illustrated vividly on the occasion when a crew visited a certain factory and by a short address to the operatives stopped a strike that had just been called.

Chasing

Such functions of M.A.P. may go towards dispelling the belief that the Ministry is nothing more than a gargantuan chasing-machine operating on behalf of the Air Ministry. It is of course that also. But so deeply has the impression taken root that

M.A.P. can only serve by chasing production that some account of its scope in helping the constructor, as distinct from chasing him, has possibly been overdue. Through no fault of the Ministry, its chasing capacities, as governed by Air Force demands, are bound to be so continuously brought to bear on the contractor that the extent to which it can be used by him are too dimly seen, and often completely lost sight of.

Regional Organisation

Every contractor is aware of the existence of the Regional Organisation, but few are aware of the actual "Terms of Reference." Early in 1942, proposals made by the Committee on Regional Organisation were accepted by the Government, and certain changes were made in the constitution and function of the Regional Organisation. Regional Boards were formed and Executive Committee advised the Boards. Generally speaking, the main purpose of the "Boards" is the co-ordination of actual and potential productive resources and manufacturing capacity of the Regions on behalf of the Ministry of Production and the Supply Ministries. In each Civil Defence Region a "Board" was formed, and is made up as follows :—

- (i) Regional Controller (Ministry of Production), Chairman.
- (ii) Representatives of Admiralty, Ministry of Supply, Ministry of Aircraft Production and Board of Trade.
- (iii) The Regional Controller of Ministry of Labour and National Service.
- (iv) Three Members representing Employers.
- (v) Three Members representing Workpeople.
- (vi) Two vice-Chairmen, one from the Employers' representatives and one from the Workpeople's representatives.

Executive Committee

The work of the Boards is directed by an Executive Committee, consisting of : The Regional Controller (Ministry of Production), who acts as Chairman ; representatives of the Supply Ministries ; the Regional Controller, Ministry of Labour and National Service ; and the two vice-chairmen.

The Executive Committees meet at least once a week and the "Boards" at least once a month and their responsibilities to the Supply Ministries are briefly as follows :—

- (1) Investigation of the capacity of all firms in the area, i.e., those firms employed on Direct Government contracts and those engaged on sub-contract work.
- (2) Formation of Group Schemes amongst firms producing like or similar equipment and stores, etc.
- (3) Advise on the desirability or otherwise of placing contracts for stores which a particular firm has not previously made.
- (4) Advise the Supply Ministries of firms who, in the Boards' opinion, should not receive further contracts, i.e., a number of firms have taken on far more work than they can hope to deliver by the dates specified on the contracts.
- (5) To deal with suggestions and complaints made by firms in the area. It should be noted here that representatives of the Supply Ministries have the right to refer any question to their particular Headquarters that cannot be settled locally.
- (6) To find and report any spare capacity to Headquarters and likewise advise on any proposal put forward by Headquarters for the expansion of any firm. Special attention being paid to the availability of labour, billets, etc.
- (7) Investigate delays in delivery, and to make to Headquarters recommendations for remedied action.

It will be seen that Supply Ministries must now refer to the Regional Organisation any questions relating to Production, Capacity, Labour and Contracts. A loophole has, however, been left to enable Headquarters to deal direct with any firm on questions of vital emergency. In the main, Regional Organisations work well, as, of course, they have first-hand knowledge of local conditions which Headquarters are not aware of.

Co-ordination between Ministries

One would ask whether in view of the duties and responsibilities of the Regional Organisation it is necessary to retain the large production staffs in the Supply Ministries. To some extent these staffs have already been dispersed to the areas but a considerable reshuffle is still necessary. Considerably more co-ordination is also necessary. At present the three Supply Ministries are competing in a limited

market for similar equipment and stores and the conditions of contract and progress payments are different. Contractors prefer to work for any Ministry in which the "Progress Payments" Scheme is so good that increased overdrafts are unnecessary.

Finance

A large number of firms have expanded their capacity many times beyond their peace-time activities to meet the ever increasing demands of the Services, and in consequence have very large overdrafts.

Banks will usually accept "assignment of contract" as security, which means that all payments are made direct to the bank. This is satisfactory to the contractor providing Progress Payments are paid regularly and he can keep the overdraft within the agreed limits. If the limit is exceeded the bank will enquire about the debentures. The contractor will then quickly contact the Supply Ministry concerned, and a solution of some sort is usually forthcoming.

There is room for improved co-ordination in the present method of placing and financing contracts. The Regional Organisations can and do help firms in this direction but the Supply Ministries, as the Ministry of Production gets into its stride, will soon be still more useful to contractors who do not fail to ask for assistance in good time,

CONTROL OF PLANNED PRODUCTION

By BRUCE FOSTER, B.C.E., D.I.C., A.F.R.Ae.S.

SOME system of planning is required in any modern factory, but the complexity of the modern aircraft and the many and varied processes involved in its manufacture make the adoption of a thoroughly comprehensive scheme an essential factor in efficient production. In order to attain any required output it is necessary that there should be complete control and co-ordination of all work going on in the factory. The organisation of the system by which it is achieved is the responsibility of the planning department. The number of parts per batch, the order of priority for work, the provision of the materials required, the efficiency of the methods employed—all come within the sphere of the planning engineer and his staff.

In describing the system of planning adopted at the Rootes airframe factory, it is first necessary to reduce it to its essential elements. The fact that the factory is required to produce aircraft at a certain rate may be taken as the starting point. This rate is defined as so many units per week or per month. In order to achieve this result the factory must have the requisite number of men and machines and must receive materials when required and in the necessary quantities. It is significant that in the production of modern military aircraft, rate of manufacture is perhaps more important than quantity. Contracts are certainly given for definite numbers of a given type, but the purchasing Government is also very much concerned with the rate of delivery. In the production of civil aircraft numbers have not reached such a magnitude that production can be said to have any great continuity, as orders are generally only for batches of the order of twenty.

With the predetermined figure in mind the planning department begins analysing the design and deciding what operations are necessary in building the aircraft. This is a very big task, as the man-hours required for each stage of manufacture must be determined, whether it be the machining of an aileron hinge pin or the final assembly of the aircraft.

Having completed this task, the number of operatives is estimated from the number of man-hours required for each operation. The number of machine tools of each type is also fixed. Numbers of operatives and numbers of machines must always be determined in conjunction, for frequently the choice must be made of doing the work by a hand process or by machine. In general, if machines in greater number, of more elaborate type are installed, the number of operatives or the type of operative will be changed.

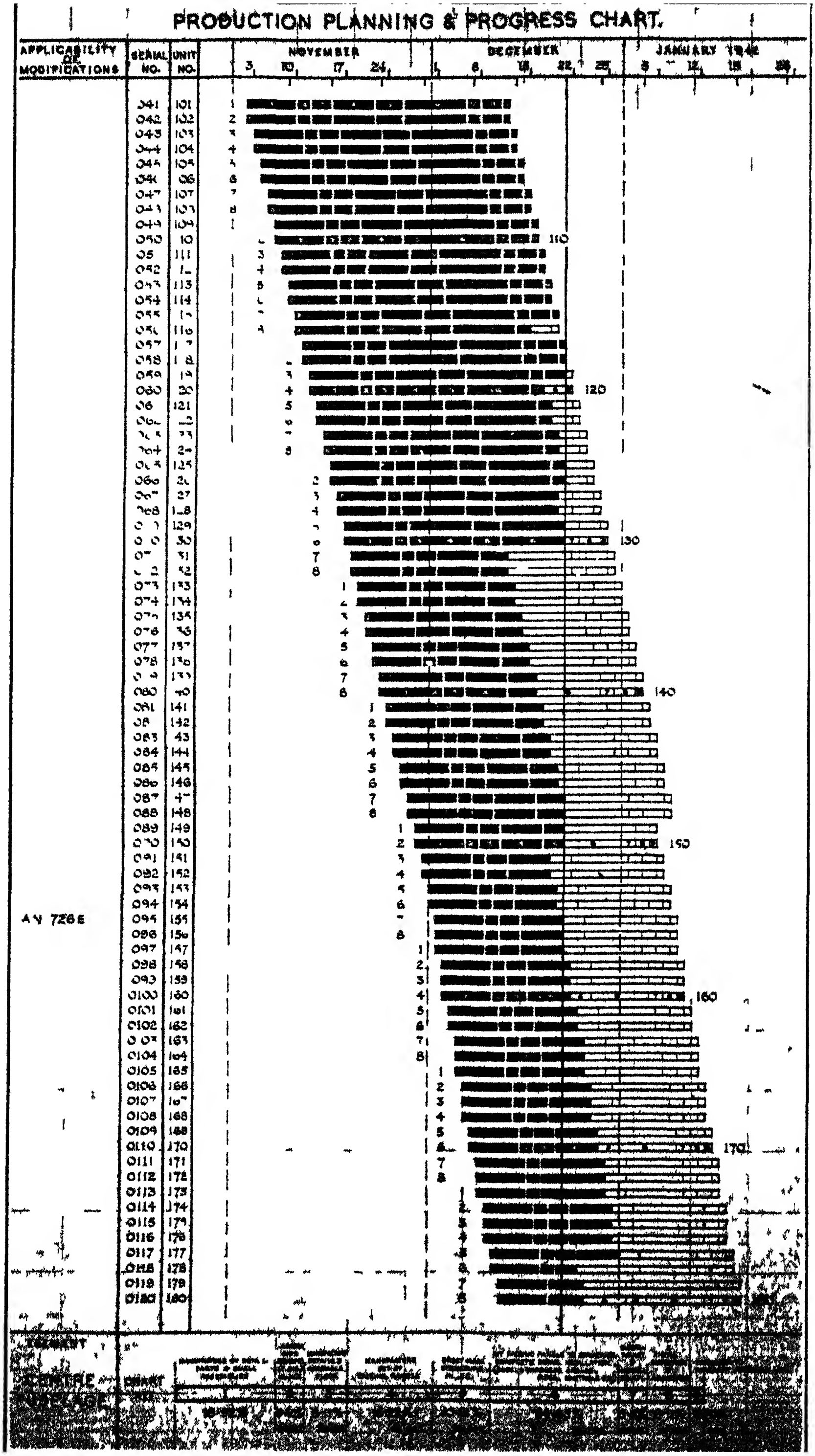

Fig. 1.—*Typical Planning and Progress Chart for the production of a centre fuselage section The horizontal bars indicate time for the manufacture of each component*

Rate of material supply is fixed simply by the rate of output of finished aircraft without reference to the number of hands or method of manufacture. Whether the material shall be delivered in batches at daily, weekly or monthly intervals is a matter for arrangement between the aircraft factory and the source of supply. In determining size of batches for delivery it must be borne in mind that the longer the interval between batches the greater must be the material storage space provided, while delivery of material to the factory must be correspondingly early. This is evident, since each batch must arrive before the first piece of material in the batch is required. If it is a monthly batch it will be four times as large as a weekly batch and will be required at the same time as the first of the four weekly batches of which it is the equivalent.

Programme Planning

The planning necessary for the efficient running of the factory is handled by the programme department and depends on the time study date which has already been compiled for each operation.

From this time study data is compiled a " time cycle chart " for the complete aircraft. The chart is built up from right to left. Working from the " fly-away date," a certain number of days, in this case ten (obtained from time study work or actual factory data), are allowed for the last process before " fly-away," namely, painting and flight trials. This fixes the date on which the previous process must be complete, which is the last stage of erection, in the present case known as EH3. The next previous stage, EH2, is then set off on the chart, working back from the beginning of EH3. EH2 requires the supply of some sub-assemblies before work can commence, and the time required for these is shown dotted at the left-hand end of the line. A full line represents the time for the completion of the work after the sub-assemblies have been received.

In this way each process is laid out, working backwards from the commencement of the one which follows it. For the centre plane this is not required for the assembly in the EH1 stage until all the sub-assemblies are delivered. Consequently, the full line of " centre plane " overlaps the dotted lines of EH1 stage. This applies to other assemblies as well.

The rear fuselage extends over the greatest period of time. The time for its manufacture is large, as it requires sub-assemblies to be built, and time is also required for the many small details to be made. The first detail for the rear fuselage is the earliest piece of work which must be started.

Fixing Starting Dates

By working on this system it is possible to ascertain just when any piece of work on the structure must be started in order that everything may be ready when required for the finished aircraft to be flown away at the date fixed. It is, of course, inefficient to have parts of sub-assemblies ready before they are required, as this means that materials have had to be delivered at too early a date. In wartime this increases the strain on the country's supply capacity, and must be avoided whenever possible.

The above statement must be qualified somewhat by saying that parts and sub-assemblies do not pass direct to the next process from the bench where they are made. No system can be made to work as smoothly as this, and it is necessary to allow a certain small margin of parts and sub-assemblies in store to ensure that there will be no hold-up in the event of a minor delay in any process.

Target Date Programme

The work of the programme department does not end with the compilation of the time cycle chart. From this another chart called the " target date programme " is built up. The horizontal base is the time scale. For purposes of illustration let it be assumed that the unit employed is the day, so that the horizontal distance between a full and a dotted line represents fourteen days; that is, two weeks. Let it also be assumed that the factory output for this period is twenty-four aircraft. The time base carries the actual dates of the period for which production is being planned, so making it different from the " time cycle chart," which is marked only with days as units of time.

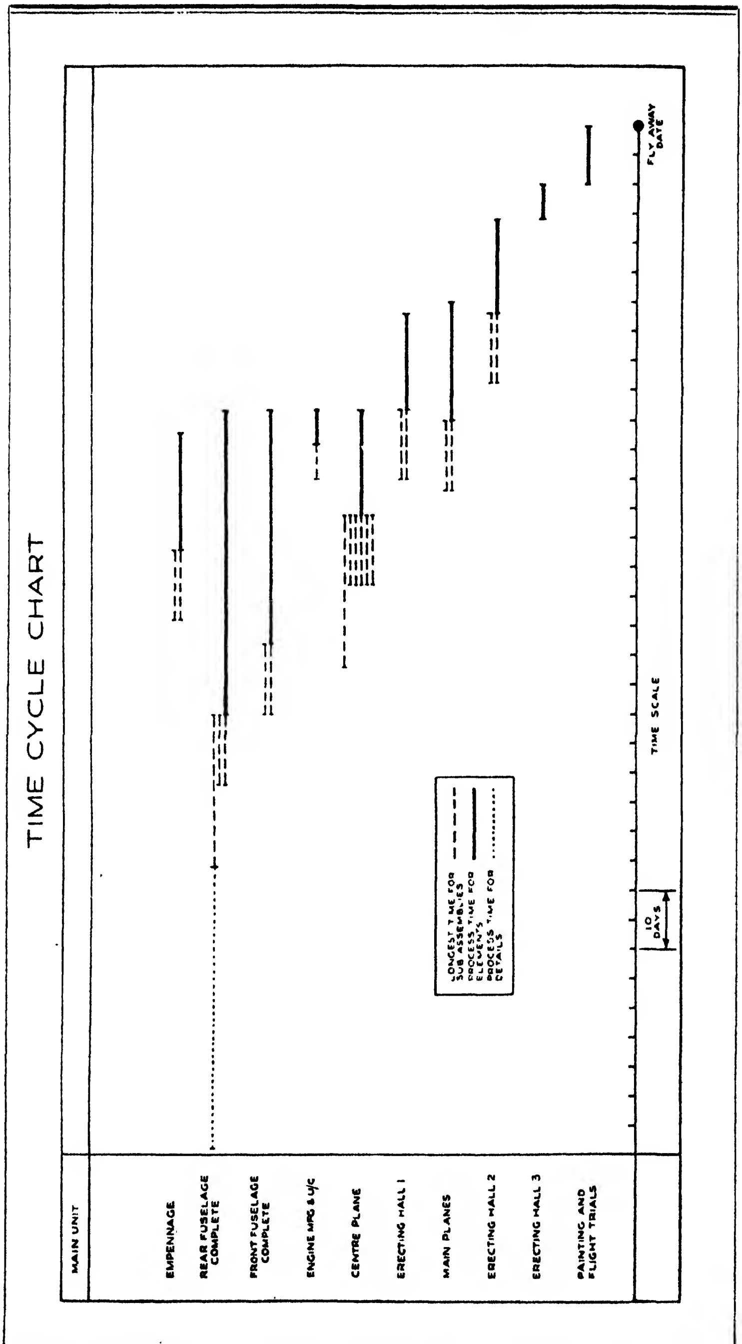

Fig. 2.—The Time-cycle Chart, prepared by setting back from the fly-away date the time required for the various operations in the order in which they must be performed. Overlapping of full and dotted lines shows how the sub-assembly work of one operation can be proceeding while the preceding operation is still uncompleted.

Listed vertically are all the parts for which details are required. Opposite each one is a vertical line which shows the date at which the details must be ready, the position of these vertical lines having been determined by means of the information compiled on the time cycle chart. The horizontal parts of the zig-zag line have no significance, and are merely to connect together the relevant set of vertical lines.

As the time between the two lines is a fortnight, and the rate of output is twenty-four aircraft per fortnight, the batch size is twenty-four sets of all details. This figure is the amount of insurance which is provided against the minor delays and slight variations in rate of flow which can occur in the best-regulated factories. It is evident that twenty-four parts must be ready before the first is needed for use, and as the last of the twenty-four is withdrawn for use another batch of twenty-four should arrive.

Batch Size

The question of batch size is another problem which comes within the responsibility of the planning department. A machine may not be engaged constantly on the production of one part, as its potential rate may be greater than that required. A certain quantity of Part P will therefore be made, after which the machine will be turned over to making Part Q. Several different parts may be made in turn on the same machine. The question arises as to how many of Part P shall be made before commencing on Part Q.

At each change the machine has to be set, and the attention of a skilled operator will be retained irrespective of the size of batch. If the batch size is small the number of settings, and therefore the cost of the part, is increased. But if the batch size is too large, material must be ordered earlier, since the last of a big batch must be completed at the same time as the last of a small batch; hence the first of the big batch must be started earlier. The disadvantage of this, particularly in wartime, has already been pointed out.

At the top of the target date programme will be noticed the target date for printing of works orders. This is almost self-explanatory, for, knowing the date when a certain set of details is required, the date is at once evident upon which the works order calling for those details should be issued to the foreman concerned.

In order to make the example definite, the time required has in this case been taken as one week, and the time scale set accordingly. In this way the work can be organised to proceed smoothly. Everyone in the factory can be told when a certain amount of work will be required of him so that the factory may adhere to its schedule, whether that work be the gluing of a batch of small wooden doors or the heat treatment of steel parts or the final assembly of a complete fuselage. The confusion which exists when foremen are issued with a large number of works orders without information as to the order of priority can be completely avoided. With proper planning, the work is done in batches of the correct size and in the correct order.

Dynamic Planning in Wartime

The description given so far of the planning work has made it appear that production conditions are entirely "static." In other words, that the number of aircraft per week is constant, that the batch numbers for the manufacture of parts are constant, and that the rate of material supply is constant also. Such a situation might obtain in peacetime, but cannot exist under war conditions. It is even doubtful whether it would be realised in peacetime, for markets are never quite steady, and just when a condition approaching steadiness is reached with regard to the production of some particular aircraft, design advances become so great that it may be necessary to cease the manufacture of the type and commence that of a new design.

In wartime, however, the "static" state is never reached; there are too many conditions which can disturb the equilibrium of flow, so that it never remains constant for very long. It may be that a change in the war situation demands an increase in the number of bombers relative to fighters; if so, the bomber factories must speed up their output. Or defence may be the vital problem for some months; the call will then be for more and more fighters. The strategical situation may change in a week, and it becomes the responsibility of the planning department to cope with the changes and to know to just what extent and in what time the factory output can be changed to supply the demands. In the modern wartime factory planning is a "dynamic" process and never stands still.

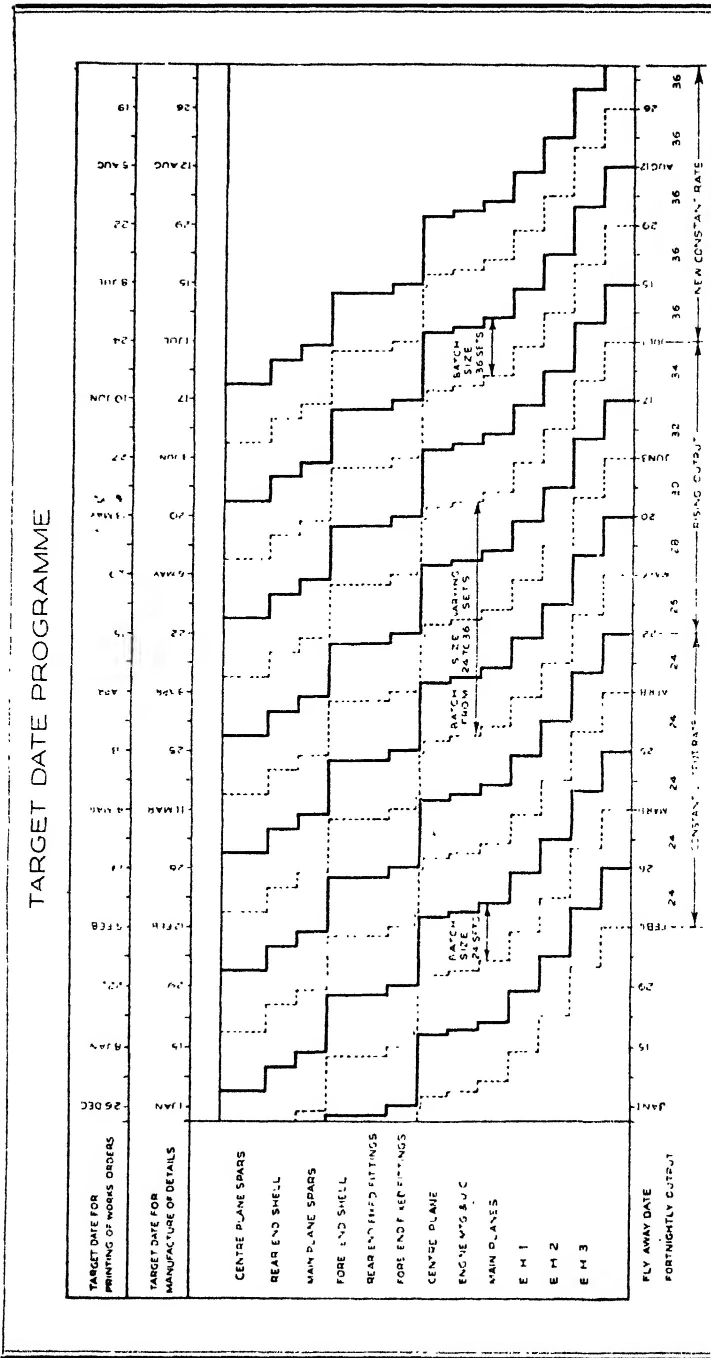

Fig. 3.—After the Time-cycle Chart is completed and the desired rate of output of completed aircraft is known, this Target-date programme can be drawn up. From it can be seen the date of completion of each batch of details, or any other operation; and the batch sizes necessitated by varying rates of output.

Increasing Production

Twenty-four machines per fortnight has been taken as an example. It might happen that the factory was required to step up production to thirty-six per fortnight; and the question would accompany the request: " How long before your factory can reach this rate ? " Obviously, it cannot be done in the next fortnight. The answer depends upon how fast extra men can be trained for the work and whether materials will be available.

This last is vital to the scheme and must be planned so that the supplies can be diverted at the appropriate time from other factories whose work is not so urgent. So on the time scale of the " target date programme " instead of a steady twenty-four per fortnight appear rising figures such as 26, 28 30, 32, 34, 36. The batch size must be gradually increased and the works orders going out to the foremen will show this in the increased numbers which they must make for the fortnightly batch. With such information no foreman need become confused, and the gradually increasing rate of material delivery at the correct time ensures that no shop will be without what it requires. Also the material stores will not be overtaxed by a sudden deluge of supplies before these are necessary.

Temporary Increase in Output

An increase of output can be obtained merely by increasing the numbers of hours worked by the operatives—this seems quite obvious. But unless care is taken to see that the supply of parts made outside keeps pace with the increased rate of work inside the factory, the increased output will only be temporary and will cease as soon as the small " pools " of parts are used up. A chaotic condition will then ensue. Unless the supply of every part is co-ordinated and the organisation maintained the production machine will cease to function.

Planning is indispensable in a modern factory of any size, but its value is emphasised in an organisation which employs numerous sub-contractors and which arranges for the manufacture in duplicate of many of the components required. Confusion would be unavoidable unless each sub-contractor could be told exactly what output was required of him for any period even with a rising schedule. Without the control given by planning this would be impossible.

As an example of the problems which the planning department must settle the aileron may be considered. Shall it be fitted to the wing during the making of that unit or considerably later, during the final assembly, when the wing is being attached to the fuselage ? To adopt the second alternative eases the supply of materials, since the aileron is made later and therefore its materials can be ordered later. But it contravenes that principle of high output by necessitating additional work in the assembly stages when working space on and around the aircraft is restricted. It is the responsibility of the planning department to balance one consideration against the other and to make the best decision.

A brief glance at the details of the planning system will be of interest. Operatives making individual aircraft parts work to a drawing of the part and a planning sheet. This is a single sheet mounted on cardboard and is issued to the operative. On it are given particulars of the operation, the tools, jigs and fixtures needed, the material required, any particulars of anti-corrosive or heat treatment and the issue of number the latest drawing to which it is to be made. The planning sheet for sub-assembly work gives the assembly of details and their order, the finished parts to be obtained out of store, and the assembly jigs and fixtures to be used. This is also a single sheet issued to the operative.

Sheets for main assembly planning are bound into books and are kept only by the foremen in charge of the assembly. There are separate books for each of the following: rear fuselage, front fuselage, centre plane, main planes and tail unit. Such a book details the order of attachment of the various parts and the stages at which inspection must be made before work can proceed further.

THE PRODUCTION LABORATORY

The Testing Laboratories of Rootes Securities, Ltd.

THE control of material quality depends on the physical and chemical testing laboratory. In this the materials are tested not only when they enter the factory but also during the production processes. For example, the quality of each high-tensile steel forging is investigated by a hardness test, and after machining each forging is put through the electro-magnetic crack detector.

All parts of the control system, every wheel, cable, chain and turnbuckle are tested and stamped. Timber from each plank is tested and the plank numbered to relate to its test piece. Frequent tests on the strength of glued joints are performed.

Welders are required to satisfy the laboratory that their work is of a consistent standard, and tests are taken at six-monthly intervals, or more frequently if the standard should appear to be falling off.

Tests are also being continually made on the strength of rivets and of riveted joints, on small welded and built-up parts, and in obtaining data for any specific purpose such as the use of alternative materials. Heat treatment is controlled by means of samples treated concurrently with the batch, and a 100% hardness test is made of the parts to investigate uniformity. For steel parts every batch of annealed material is sampled, and the sample heat-treated in the laboratory to give the required mechanical properties. The information so obtained is supplied to the heat-treatment department in the form of an instruction applicable to the particular batch.

The Chemical Laboratory

On the chemical side a strict control is kept on anodic treatment, cadmium, nickel and chrome plating, and on the chromate treatment of light magnesium alloys. Tests are taken daily from every vat and the test pieces checked for weight and quality of deposit. Paints and enamels are kept to close limits of viscosity and test pieces taken are checked for weight and adherence of paint film. The testing of rubber parts for resistance to petrol and oil and the testing of extracts from cork and Langite jointing materials for acidity are other typical tests on raw materials which the laboratory carries out. By use of the pH meter the laboratory is able to investigate the tendency of any two materials in contact to corrode, and by similar methods the acidity of paint films between metals is checked.

On the physical side a considerable amount of metallography is carried out, and the Vickers microscope is in frequent use. Photo-micrographs are taken at various magnifications from 100 to 3,000, chiefly in the investigation of failure or in the checking of heat treatment. The equipment includes a thirty-ton Amsler universal testing machine, suitable for tension, compression and bend tests, a 4,000 lb. Amsler tensile machine for thin strip material, a Vickers pyramid hardness tester and an Avery Izod machine. A small Wild-Barfield electric furnace with gas atmosphere is used for heat-treatment work.

The chemical equipment includes a Sartorious air-damped automatic balance, a Cambridge potentiometer and a direct reading pH meter, a tube furnace for combustion carbon in steel, a muffle furnace, a standard distillation apparatus, an oven thermostatically controlled within limits of $\pm$ 1° up to 300° C., and a thermostatic water bath.

The Standards Room

This room stands in relation to dimensions of the finished product as the laboratory stands to material quality. All dimensional control originates from it. It is built inside the factory but is on its own foundation and is completely isolated. It is also insulated from the factory as regards heat, sound and dust, and is completely air-conditioned, a constant temperature of 68° F. being maintained. Air enters at the ceiling and is exhausted at the floor. Lighting is by a special combination of coloured neon tubes, producing a daylight effect.

In this room are kept the standards of measurement in the form of Zeiss and Pitter blocks and length bars which have been approved by the National Physical Laboratory and upon which the whole of the factory measurements are based. Parts are made to gauges, and it is the duty of the standards room to set and check every gauge to the limits required.

Special equipment, tested by the N.P.L., has been provided which enables measurements to be made to the very high degree of accuracy of 0.00001 inch. Gauges are checked to 0.00005 inch.

Measuring Equipment

An impressive range of measuring equipment is employed in the standards room. It includes Cussons screw measuring machines, vertical measuring machines, a projector and toolmaker's microscope, a horizontal optometer for internal and external measurement, orthotest comparators, surface plates, optical flats, protractors, verniers, and sensitive micrometers.

From the gauge stores which adjoins the standards room gauges are issued to every part of the factory. These are recalled from use at regular intervals of one to three days for re-checking in the standards room. Screw gauges are checked on projectors to ensure that the thread form is correct. Gauges for the larger components are also checked in the standards room, which is responsible for the interchangeability of all such units. With the equipment provided, measurements up to fifty feet can be made to a high degree of accuracy. Records are kept of every check made, and from these records much valuable data is obtained as to the life of gauges made from various grades of steel.

DESIGN AND DEVELOPMENT IN WARTIME PRODUCTION

By F. H. M. LLOYD, A.F.R.Ae.S.

(*Hawker Aircraft, Limited*)

It is of vital importance that in wartime the introduction of a new type of aircraft on to the production line should be achieved in the absolute minimum of time. The continual struggle between the opposing sides for both technical and tactical superiority in the air gives rise to constantly changing requirements which have to be met by the aircraft designer and constructor.

Urgent Requirements for Fighters

At the beginning of the present war we found ourselves in the possession of a comparatively small Air Force, composed of aircraft which were in the main superior in quality and performance to corresponding enemy types, and manned by pilots and crews of unquestionable superiority. So, although we started in a strategically inferior position due to lack of numbers, we did have a slight technical lead. Obviously the need was for numerical strength, and the aircraft industry was geared up to produce in ever increasing numbers the types existing in September, 1939. This applied particularly to fighters, since the first thing to ensure was that our Air Force should not be destroyed on the ground in the same way as were the Polish and, to an extent, the French Air Forces. The results of the Battle of Britain justified this policy, but our fighter strength was, of course, depleted during August and September, 1940, and it was necessary to bring the numerical strength up again by continuing the drive to turn the maximum number of fighters off the production line. Production personnel all over the country, from General Managers to Progress Chasers, from Works Managers and Foremen to unskilled labourers, certainly made a first-class job of this, and through their efforts we were able to survive a period of extreme danger.

It followed that, with the maximum effort and all available men concentrated on turning out existing types of aircraft, there could be no question of introducing new types into production during that time; and, like a camel living on its hump, we lived for this period on our small technical lead. The introduction even of modifications on to the production line was frequently opposed or delayed on the grounds that they would interfere with the smooth flow of production, and cause a drop in the monthly figures.

Maintenance of Technical Superiority

While this lack of development was unavoidable, it was obvious that it would only be a matter of time before we should lose our technical superiority, since during the first two years of war the Germans had less need for concern over their fighter strength, and were in a position to introduce more advanced types into production

The danger was that, having built up our fighter strength to the numbers required the position which existed on the outbreak of war in 1939 would be reversed. Namely, that the enemy would gain technical superiority, while we achieved a superiority in numbers, and they would then be in the same position as we were when we won the Battle of Britain.

Development could not be neglected, and the greatest effort had to be made to maintain the technical lead by introducing essential modifications to existing types of aircraft, and by speeding up the introduction of new fighter types.

High speed combined with heavy armament is essential for the interception of fast modern bombers, but for air-to-air combat between fighters, the fighter which has the advantage in both vertical and horizontal manœuvrability may sometimes gain the mastery over the faster but rather less manœuvrable fighter. In another dimension, it is useless to design our fighters to give their best performance at low altitudes if the enemy are going to take all their bombers into the stratosphere, and it is equally unavailing to design for operation at 45,000 feet if the enemy decide to use only "hedge-hopping" tactics.

Initiative in Design

It is not possible to forecast the enemy's moves accurately two or three years ahead, unless we hold the initiative in design. By keeping technically in advance of the enemy we force him to follow our lead by compelling him to introduce complicated modifications to counter our moves, and to change his types frequently. We know what dislocation of production is caused by the frequent and rapid introduction of major modifications. The change over from one type to another, even when the obsolescent type is slowly "tailed off" as the new type is gradually introduced to full-scale production, cannot be achieved without the loss of a million or more man-hours. This loss of time is serious when one is racing to make up technical deficiencies; it can be fatal when the necessity of making up numerical deficiencies is also present.

Summarising the position: in the single-seater fighter class our technical lead was temporarily reduced, though we have never slipped behind. This has been due to our initial need for numbers at the expense of an advance in development. Numerically, we are now as strong as if not stronger than the enemy, and the combined output of the Allies is considerably greater than that of the Axis. We are, therefore, in a position of advantage, and provided we always act quickly we can call the tune in aircraft design, and force the enemy to follow our lead defensively.

To achieve the maximum possible output is still important, but it has become second in importance to the need for rapid technical advance and development. Modifications that are operationally necessary and the introduction of new types must never be delayed in future, because they have an adverse effect on production. On the contrary, they must be introduced rapidly with the minimum of interference to production.

Introduction of a New Service Type into Production

During the initial discussions with the Air Staff and M.A.P., which should not take longer than two months, project and mock-up drawings should be prepared. This will allow the specification to be defined and most of the details to be settled. At the end of these discussions it is absolutely essential, in order to give the contractor full powers to proceed with the ordering up of materials, that both a prototype order and a substantial production order should be placed at the same time. The peace-time procedure of giving a production order after the approval of the prototype is out of the question since this will more than double the time taken to introduce the type. Risk of scrap must be taken, and as an insurance policy it may be advisable to place contracts with two firms, each to produce an aircraft of their own design to the new specification. In order to avoid too great a multiplicity of types, the number of firms producing aircraft to a single specification should not, however, exceed two. If the engine selected is fully developed and the engine production position is assured, reliance can be placed on one engine type. If, however, the engine is in an early stage of development, provision must be made for the use of alternative power plants.

Commencement of Drawings

As soon as the prototype and production orders are received work can commence on the experimental drawings for the prototype, and the first of the production drawings can be started within two months, the mock-up conference and final decisions being taken between those dates. This assumes that the decisions taken at the mock-up conference are not altered and that there is no change in Air Staff requirements.

Pre-Production Planning

Discussion with Material Controllers and ordering of materials should begin simultaneously with the commencement of the production drawings. The pre-production departments must be geared to exert a continuous pull on the drawing office, and must always be seeking advance information. Complicated stampings, castings and extrusions must be ordered well ahead, so that these do not become shortages and lengthen the time taken for the acquisition of complete sets of parts. A system of classification of parts is most necessary at the processing stage. The most highly complicated parts, which are likely to give rise to the greatest difficulty in manufacture and delay in delivery, should not amount to more than a dozen or so in a well-designed aeroplane, and these should be the personal concern of the head of the pre-production departments up to the time of their delivery. His most experienced men should progress all other forgings, castings, extrusions, etc., of a less complicated nature, and his general rank and file should look after the simple, straightforward parts which compose the vast majority.

Semi-Tooled Methods

One of the main causes of delay in the past has been the time taken to complete basic jig and tool manufacture. Nowadays it is the practice to sub-contract a portion of jig and tool design and manufacture, but a greater degree of standardisation of tool parts is still necessary. The first production aeroplanes are partly produced by semi-tooled methods and it would undoubtedly eliminate many of the teething troubles and subsequent major modifications to production aeroplanes after they have been in service, if these methods were extended still further.

The operational and serviceability qualities of a new type cannot be properly judged until sufficient aeroplanes are available for a squadron to operate under active service conditions. At present, by the time those numbers of aeroplanes are in service, tooling has been largely completed, and the rapid incorporation of major modifications, which are invariably found necessary as a result of Service experience, becomes extremely difficult and costly. If, however, about twenty "pre-production" aeroplanes were built alongside the prototype by experimental and semi-tooled methods, and delivered to a Service squadron within four to six months after the approval of the prototype, most of these modifications could be incorporated before quantity production begins. This requires the existence of a large and powerful development department, which many firms do not at present possess, whose duty it would be to build these "experimental-production" aeroplanes, modify them to current Service requirements, and maintain very close liaison with the production departments. This department should also be employed to modify all production aeroplanes to full operational standard without any interruption to the production flow. The department must be part of the parent firm, and, difficult though it may be to find the skilled labour, the benefit to production and to the Service is such as to justify their transfer to this side of the works.

Modifications

An efficient production organisation is of necessity too inflexible to allow the rapid introduction of major modifications on the production line, and if we are to increase our technical lead a development department becomes just as essential a part of the organisation as the experimental department. It must be realised that war conditions are liable to give rise to a high rate of obsolescence, and consequently that design can never be finalised at any stage. To attempt to do so would run the risk of producing an aeroplane which will no longer serve the main practical purpose for which it was ordered, and which may be the cause of the loss of many valuable lives in air combat against superior enemy machines. At the same time, frequent alterations during the design stage will delay the introduction of a new type very seriously, and the longer the delay, the greater will be the number of modifications required.

Restrospective modifications of a minor nature can be carried out at squadrons by working parties under the direction of the development department, or when aircraft are in for repair. They can generally be introduced on the production line without great difficulty.

If an attempt is made to introduce a major modification directly on to the production line by semi-tooled methods, modifying aircraft as parts become available, the production output drops steadily until full sets of tools become available, and this is obviously impracticable. What happens in practice is that the introduction of the modification on to the production line is delayed until there are sufficient parts to modify all aircraft, and, unless there is a lot of scrap involved, production output is scarcely affected. However, urgent modifications which are vitally necessary from a production point of view may be delayed for six months or more.

By making the necessary parts by semi-tooled methods in the development department, it is possible to commence the modification as soon as it is approved, and enough parts can be provided for the modification of all aircraft on the production line in a comparatively short time. This feeding by the development department continues until complete sets of tools are available, when it is tailed-off as the fully tooled sets of parts are introduced.

The object of the development department, then, is to speed up the introduction of new service types and of modifications to existing types.

Avoidance of Changes by M.A.P.

During the building of a new type, the contractors should be given every assistance by the Air Staff and M.A.P. Once the details of a new specification are decided upon, they should not be altered without reasons of the utmost gravity, since an alteration may mean months of delay. Continuous meetings and discussions with individual officials from various branches of the Ministry should be avoided. Periodic meetings should be arranged well in advance when representatives of the various Ministry departments affected should be invited, in order to arrive at the best compromise for the greatest operational efficiency of the aeroplane as a whole. It is otherwise difficult to convince a specialist of one particular branch that his demands, while ideal from his point of view, lower the operational efficiency of the aeroplane as a whole, for instance by the addition of weight. His demands, which may involve only a few pounds extra weight, seem reasonable enough to him, but the accumulation of a few pounds here, there, and everywhere all over the aeroplane, demanded by wireless, electrical, armament, equipment, heating, fuel system, armouring, maintenance and the many other specialists, if accepted by the contractors, can well add several hundred pounds to the fully loaded weight of the aeroplane which, particularly in the case of a fighter, may be disastrous.

Furthermore, the greater the number of changes made during the design and pre-production period, the longer it will take to introduce the new type into service. It must now be the first aim of the British aircraft industry to produce new types which are so far ahead of those of the enemy in all aspects of performance and armament, and the quicker they are produced the greater will be our technical and tactical lead.

INTERCHANGEABILITY

By B. KAISER, A.F.R.Ae.S., A.M.I.Mech.E.

The subject of interchangeability is of special interest to those engaged in the design, production and servicing of aircraft. Many of the problems encountered are peculiar to the industry and require much more comprehensive consideration than in any other branch of engineering. In the early days of the industry the attainment of interchangeability was relatively simple. It was only necessary to see that mating parts were manufactured to the correct limits, that attachment hinges were carefully positioned, and that control surfaces had freedom of movement. All this could be done with very simple equipment.

To achieve the interchangeability of the sub-assemblies required in modern aircraft, however, methods must be brought into line with current production practice.

Interchangeability is seldom attained on the first few aircraft of a new type. Various assembly troubles have to be eliminated gradually as parts become jig built and gauged. Also, when components are extensively subcontracted, as is frequently the case, reproduction of identical jigs and tools presents a very serious problem.

It is proposed to discuss the subject under the following headings :

(i) Definition of interchangeability.
(ii) Component and detail part interchangeability.
(iii) The interchangebility of pipes, electrical and hydraulic systems.
(iv) Standardisation.
(v) Aircraft drawings and limits.

Methods of interchangeability will then be considered, including jig references, interchangeability gauges, the design and checking of jigs, and the use of standard parts and master gauges.

Interchangeability of a part denotes that it may be replaced by one made to the same drawing without the need for adjusting either the part or the aircraft to which it is fitted. A strict interpretation of these requirements would, however, preclude both fitting and reaming during assembly and service repair. It is therefore agreed that the amount of fitting required on assembly to fit new parts is a matter of degree.

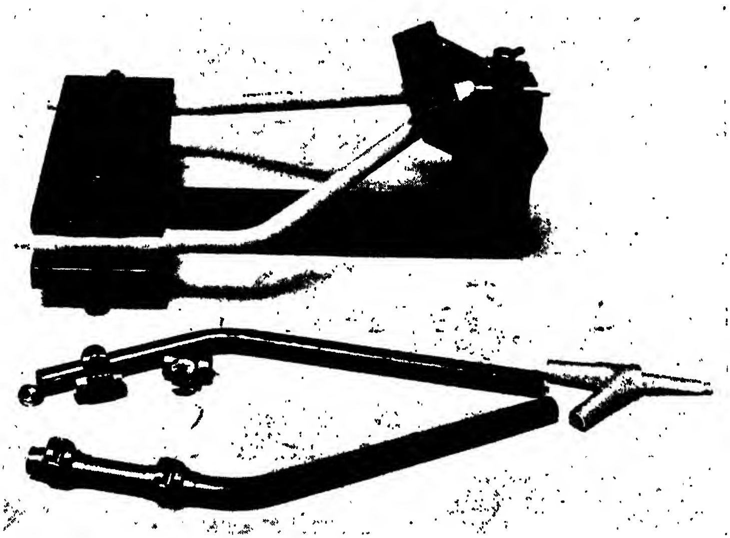

Fig. 4.—Jigs for the production of interchangeable tubular units.

Take, for instance, the replacement of a fuselage strut; it should be possible to do so simply by inserting bolts or tie-rods and ferrules through the old and new parts. Where a repair is carried out to a damaged section of a main plane, however, the amount of work necessary to build up the damaged structure means that the reaming of two or three holes on assembly is a very small operation compared with the work entailed in rebuilding the damaged parts. This is particularly so in the case of the monocoque type of construction.

Considering the question from a salvage point of view, the advantages to be obtained in using parts of crashed aircraft in new machines are obvious, subject to the proviso that these parts conform to design requirements and are rigidly inspected before re-use. The degree of interchangeability is again involved in the case of semi-riveted joints. To re-make a joint of this nature without the original contractor's equipment and jigs is practically impossible at Service aerodromes, and usually a contractor's working party is sent out to do the job.

There are three fundamental ways of joining parts :

(i) Making them integral with one another by the application of heat, as by welding, soldering, or brazing.

(ii) Riveting.

(iii) Securing by bolts and nuts or tie-rods and ferrules.

To be classed as interchangeable, a part should be capable of being readily detachable from its mating part. Welding and riveting are therefore eliminated as methods of joining parts so that they may be interchangeable.

Present-day practice in the aircraft industry generally limits the attainment of interchangeability to components and sub-assemblies, a defeatist attitude being adopted whenever the interchangeability of detail parts is mentioned. The design of the main attachment points is a deciding factor in component interchangeability. This, of course, depends entirely on the type of structure. A stressed-skin structure, with loads distributed over a wide area, rarely lends itself to the easy attainment of interchangeability between components, as the designer is usually reluctant to adopt the relatively inefficient practice of concentrating his loads on a limited number of "pick-up" points. The use of numerous small bolts and gusset plates for main

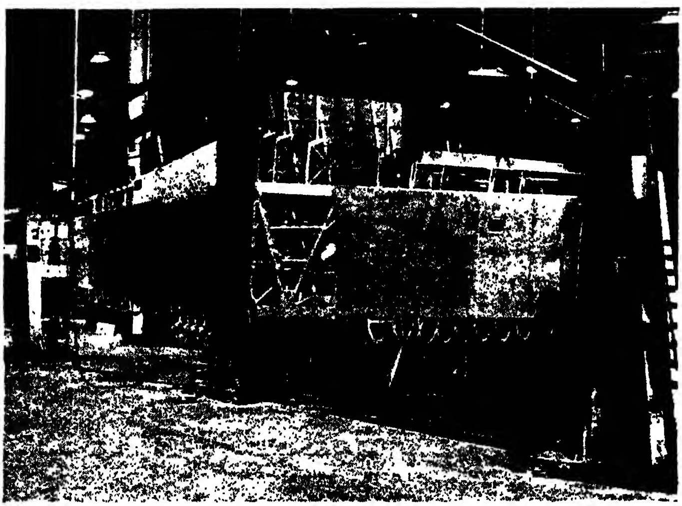

Fig. 5.—A typical jig for main component assembly.

attachment joints makes the jigging and gauging of the joint very costly and difficult to produce, and invariably results in reaming on assembly with its consequent lack of interchangeability.

Simple single-pin male and female joints with laminated peel-off shims and replaceable bushes are probably the easiest to jig for interchangeability. Furthermore, if wear occurs after a period of service, new bushes can be inserted in the joint with a minimum of trouble, so ensuring the fit and future interchangeability of components.

Experience shows that ball and socket joints are difficult to jig, considerable variation in alignment of the components occurring on final assembly. It is also very difficult to correct any manufacturing errors that may occur between the ball and the socket. There is a welcome tendency to provide split bushes and tapered cones in main attachment joints, which is a considerable aid to interchangeability and assembly. Slight variations between two mating parts can often be accommodated by such a joint. In many cases, a good type of main attachment joint is spoilt by the addition of struts and/or gusset plates which are not adjustable.

To reduce inflexibility and to facilitate handling and transport, the components of an aircraft must be limited in size, so that they may be accommodated by existing

facilities. These components may number as many as thirty per aircraft. They must all be readily interchangeable and free from unnecessary projections which may be damaged during handling or transport. Further complications are introduced as a result of the necessity for limiting the size of components. Flaps or bomb doors may extend over two or more components, all of which will be subject to rigging variations, whereas the flaps and doors may themselves be subdivided into smaller units. Adequate clearance in the pick-up points of such components is strongly advocated with adjustable hinges on at least one of the mating components. A datum or thrust hinge should of course be provided on each component, preferably near the centre.

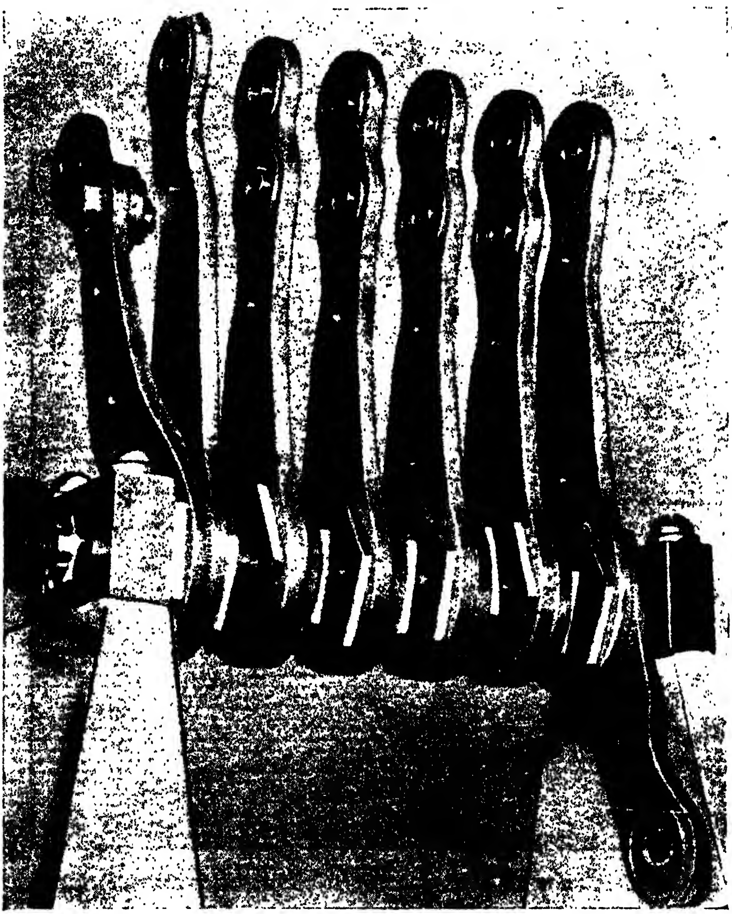

Fig. 6.—Various types of Junkers control levers, standardised parts.

Detail Part Interchangeability

Interchangeability in aircraft detail parts is often regarded as an evil made necessary by some obstinate Air Ministry official. In fact, detail interchangeability is of inestimable value to the aircraft contractor. In these days of large-scale production and decentralisation, with the possibility that two or more remote sub-contractors are manufacturing the same parts, it is of great advantage if the assembly plant can fit

a detail without drilling or fitting " to suit." Interchangeability of detail parts can only be achieved if the following fundamental points are recognised:

(a) The correct use of a limit system on aircraft drawings, coupled with adequate dimensioning to three or more places of decimals, all, if possible from a common datum. " Chain " dimensioning is much too prevalent on drawings.

(b) Tools used for the manufacture of the detail parts must be accurate, and where more than one particular tool is in existence these must be identical.

(c) The inspection department must work to drawing.

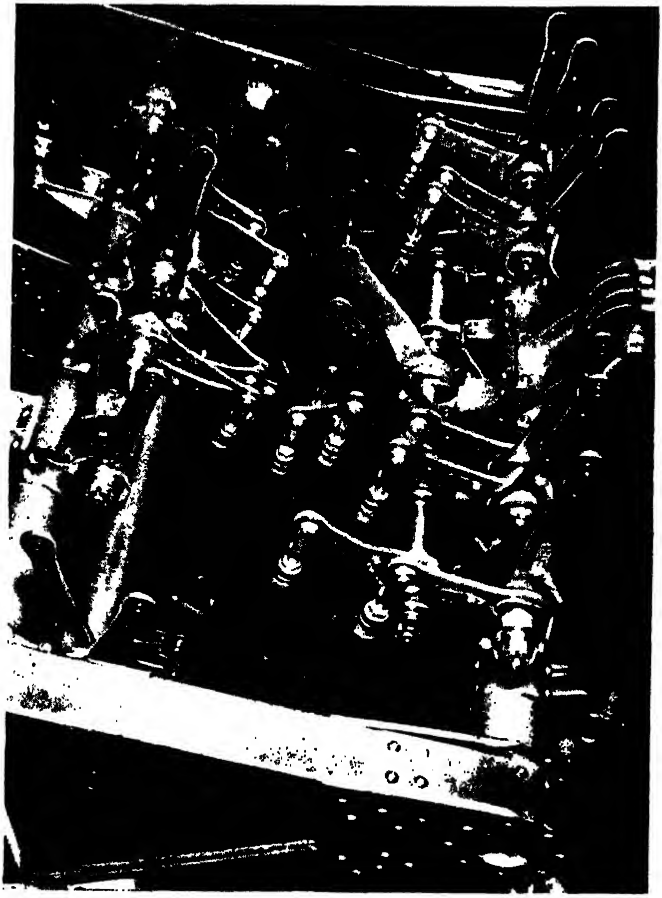

Fig. 7.—A close-up view of part of the installation shown in Fig. 8.

Two or more sub-contractors may be engaged in producing the same part, and even though these are produced in jigs, discrepancies always appear between parts from the different makers. The provision of tools for producing the parts is usually made the responsibility of the sub-contractor, who more often than not has only limited toolroom facilities. Invariably he places an order for the tools with a toolmaker specialising in this work, with the result that direct contact with the parent firm is lost, and the settlement of drawing and producing queries becomes a laborious and lengthy process. Finally, a drawing query is probably either neglected or settled on the spot by the individual toolmaker.

Tool Drawings

Owing to the urgent demand for tools, the preparation of tool drawings from the aircraft drawings is often neglected. Reliance is frequently placed on the aircraft drawings, and a sheet of toolmakers' instructions, with perhaps a sketch of a standard type of tool. This means that the toolmaker must work to aircraft drawings which are not suitable to the production of tools. In many cases these are insufficiently dimensioned, have sizes calculated to the second place of decimals only, and make use of angular dimensions. The use of co-ordinate dimensions based on one datum hole simplifies work on the jig-boring machines and avoids the necessity for laborious calculations in the shops.

It is often found when setting large assembly jigs that the dimensions given on the aircraft and jig drawings are not suitable for jig building. Datum points are used which are difficult to reproduce in practice, with the result that new dimensions must be calculated which are capable of being measured by existing equipment. Another reason why the interchangeability of detail parts is seldom achieved is the tendency

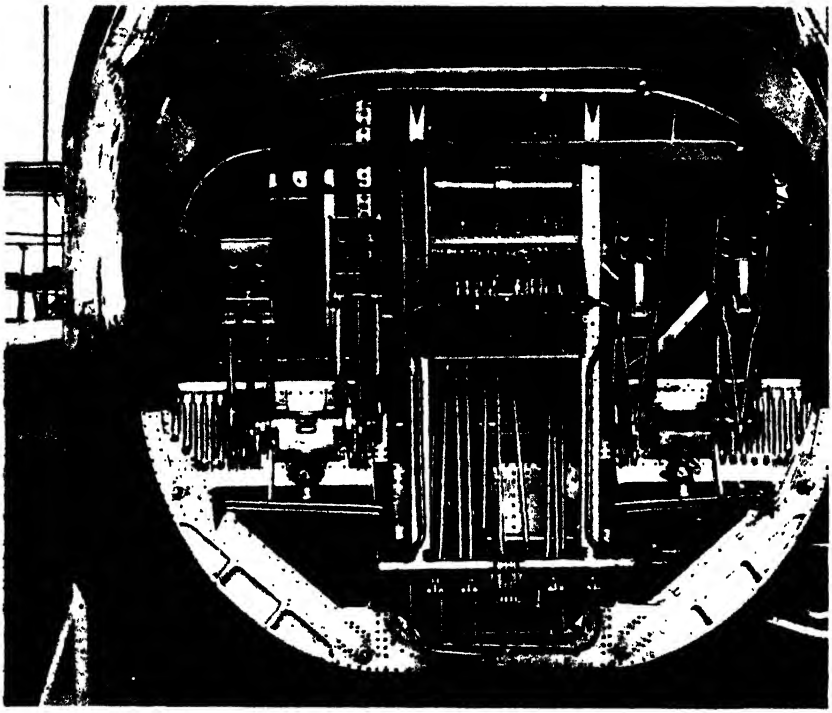

Fig. 8.—Arrangement of the operating rods from the cabin of a Junkers twin-engined machine. Standardised control fittings are used.

of sub-contractors to leave from 0.010 inch to 0.015 inch in the holes for the correction of discrepancies which may occur on the assembly of the parts. This practice has, no doubt, been brought about by their practical experience in tooling up components from aircraft drawings. Possibly the greatest obstacle to the achievement of interchangeability, however, is the number of alterations to detail parts which are made every day and are likely to continue throughout the life of the aircraft.

It is agreed that the basic structure of the aircraft is not so susceptible to these changes, but there are associated sub-assemblies which change their drawing issue number in a bewildering manner. Considerable time, therefore, is spent in re-checking tools to the latest issue of the drawing so that alterations to the tools may be made if necessary.

The alterations to the drawings may be due to :

(*a*) Initially incorrect dimensioning.

(*b*) Alternative methods of manufacture.

(*c*) The addition of new systems or equipment necessitating the re-design of existing parts.

(*d*) Existing parts may have been found unsuitable.

Factors influencing detail interchangeability are hole sizes, hole centres and overall clearances, each of which may be affected by the alteration. A certain number of aircraft may be fitted with a detail part to issue 1 of the drawing, and subsequent aircraft may have a part made to issue 2 of the drawing. It often occurs that parts made to later issues of the drawing will not replace parts made to the earlier issues, with the result that the operation of a spares and repairs system becomes extremely complicated. It is necessary for the Service personnel or repair organisation to hold spare parts to all issues of the drawings, so that any part may be replaced without the necessity for reaming or adjustment. No scheme of repair or maintenance can be operated efficiently when the detail parts are subject to constant alteration.

Another factor influencing detail interchangeability is the large tolerances permitted on tube diameter and gauges of material, although these are no doubt necessary for more rapid manufacture. Take, as an example, the case of a strut between two spars in plane bracing. The spar booms may vary $\pm$ 0.015 inch on outside diameter. In addition, tolerances of 0.015 inch may be permitted on, say, a vertical gusset interposed

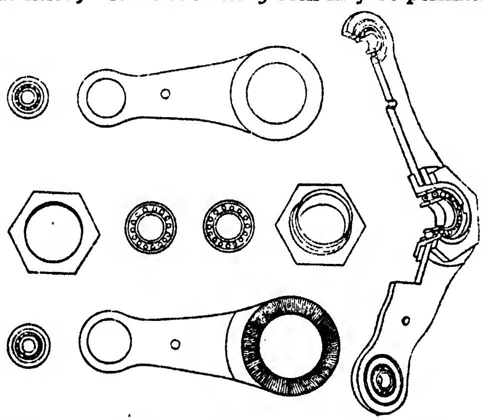

Fig. 9.—The standard parts comprising the bell-crank levers shown in Fig. 6.

between the strut bracket and spar. Variations in strut lengths up to 0.060 inch may occur in such cases, making it impossible to jig the overall length of the struts. Intelligent design can, however, solve many of these problems by the use of adjustable struts or shims, although it is agreed that the first method may involve considerable additional weight. Methods of improving the interchangeability of detail parts will be discussed later.

Interchangeability of Equipment

In joining the front fuselage to the main plane centre section of a large aircraft, the complicated mass of subsidiary joints is the major problem to be tackled if interchangeability in its true sense is to be achieved. Compared with the joining of the control systems, pipe lines and electrical services the fitting of the main attachment bolts is a very small job. All the systems and controls in the aircraft usually lead to the front fuselage.

These systems may be summarised as under :

(*a*) Flying controls.

(*b*) Subsidiary controls, air intake, airscrew, cockpit heating, etc.

(*c*) Hydraulic pipe lines for turrets, undercarriage flaps.

(*d*) Vacuum pipe lines for instruments.

(*e*) Air pressure pipe lines for brakes, automatic controls, de-icing.

(*f*) Petrol and oil pipe lines.

(*g*) Oxygen pipe lines.

(*h*) Electrical services.

(*i*) Instrument capillaries.

In each system a special method of joining is employed. In the case of the controls, fork ends, shackles or turnbuckles may be used. These are usually adjustable so that the cables and rods may be tensioned. There are many proprietary types of flexible controls. In general, these end in a fork joint, and are capable of adjustment. The replacement of such controls is, therefore, fairly simple. However, to ensure that the range of adjustment necessary for tightening the controls is available, it is necessary to determine the length and layout by means of wire templates taken from the prototype or first production aircraft. This method is also used for pipes, jigs being constructed from the wire templates when completed.

With regard to pipes, the type of joint varies considerably, careful jigging being necessary to ensure the overall length from joint to joint. The olive and cone joint seems to be predominant on the various systems, and does not allow for variations in the position of tanks or jacks. A joint such as the Simpliflex, where a light alloy ring is pressed on to the outside diameter of the pipe, is much better from an interchangeability point of view. Spare pipes can be supplied with perhaps a $\frac{1}{4}$ in. left on the end, as it is a fairly simple job to adjust the length to suit the position of the units to be connected.

It is very difficult to guarantee the position of tanks owing to the method of support. Usually cradles lined with shock-absorbing material are used for this purpose. The tanks themselves may be also covered with a leakproof layer of resilient material. The use of flexible metal-braided pipes for joints which are likely to vary permits such variations to be ignored, whilst a leakproof joint can be maintained.

Electrical services in each component terminate in an imposing array of terminal blocks or loose wires, which have to be linked to the corresponding terminal block or wire in the other components. The possibility of wrong connections and the time taken to connect the electrical services into one continuous circuit, make the development of unit plug-in terminal panels essential. A step in the right direction is the Breeze system of plug-in circuits, where each conduit carries a particular service such as bomb gear release or navigation lights. Orderly grouping of pipe joints and electrical panels at the end components, as instanced by the Bristol power unit, would facilitate the rapid assembly of components and relieve the congestion which occurs at the main attachment joints.

Standardisation

No doubt the present high quality of our first line aircraft is due in a large measure to the policy maintained in the past of non-standardisation of detail parts. Individual firms have been allowed full scope in developing their own products and the resulting competition has improved the product by the development of new ideas. However, to attain rapid production under present conditions the number of different parts required per aircraft must clearly be limited to the minimum. The aircraft must include as many standard parts, common to all types, as possible. To achieve standardisation there must be a much stronger authority than hitherto, as each firm regards its product as the one which should be adopted. Furthermore, standardisation should be adopted gradually as the avoidance of scrap or delay in production is of paramount importance. It is of interest to review the attempts at standardisation that have been made.

A wide range of standardised details known as A.G.S. parts are available, including bolts, nuts, unions, couplings and similar parts. In the case of bolts, however, aircraft drawings often carry a note stating that bolts can be made from A.G.S. bolts, with the result that production time of such parts is practically doubled. No doubt the procedure of making special bolts from A.G.S. bolts is justified by the specific requirements of the designer. The whole question of making A.G.S. parts suitable for specific purposes, however, needs thrashing out in collaboration with aircraft designers. A wide range of proprietary items of equipment has been approved for fitting to aircraft, and such items as wheels, cocks, filters, jointing materials, pulleys, are included in the list. In many cases two or three firms supply the same article, but with varying detail design.

A further contribution to standardisation has been made by firms who specialise in the design and manufacture of special equipment such as turrets, oleo struts and instruments. It is suggested, however, that this tendency to standardisation is the result of the preponderance of the larger firms' products over those of smaller firms,

and of specialisation on a particular piece of equipment. The experience gained by specialisation on equipment, such as hydraulic systems, has resulted in the choice by aircraft designers of the schemes of only large firms. It is very often found that similar pieces of equipment, hydraulic jacks, flow control valves, selector units are standard on more than one type of aircraft. A still further contribution to standardisation can be made, as up to the present very little attempt has been made to standardise pilots' seats, control columns, rudder bars, petrol tanks, throttle controls and other items.

The issue of Aircraft Design Memoranda and Standard Instruction sheets by a central organisation is a further attempt to achieve standardisation. Some degree of uniformity can be secured in cockpit layouts, instrument panels and automatic controls if the collaboration of the aircraft designers is obtained. A successful application of standardisation is the blind flying instrument panel which is fitted to various types of aircraft. This contains an altimeter, gyro-horizon, turn indicator, air speed indicator, gyro-compass and a rate-of-climb meter, the complete panel being interchangeable by removing three bolts and the instrument connections. Personnel engaged in the fitting and servicing of such panels are also interchangeable and can be employed without special training on all aircraft equipped in this manner.

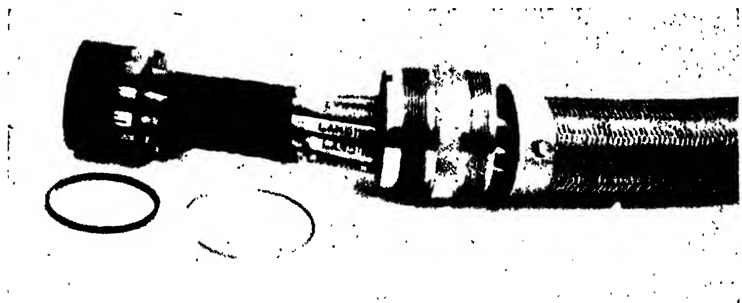

Fig. 10.—*A dismantled Breeze plug.*

Standardisation of Materials

Standardisation of materials is attempted by the issue of D.T.D. and B.S.I. Specifications. As there are over 300 D.T.D. Specifications and approximately 170 B.S.I. Specifications, however, the question must be asked: Are all these specifications necessary? Specific requirements of designers must be recognised, but the importance of quantity production must come first. Some reduction in the number by eliminating overlapping specifications is essential.

There are no fewer than twelve firms supplying hydraulic pumps for operating items of equipment such as undercarriages, gun turrets, automatic pilots and flaps, each firm manufacturing anything from two to nine types. The divergent competition now existing between the makers of hydraulic pumps could be transformed to concentrated production of a standardised range of units suitable for all purposes. A large number of plugs, sockets and minor items of electrical equipment are necessary for the various electrical systems in aircraft. Plugs are required for inter-communication, wireless, auto-control system, instrument and general services. It is considered that a great number of the electrical fittings in the various systems could be replaced by a small number of universal types. A large number of detail parts fitted to aircraft are handed port and starboard. Consideration of such parts in the design stage from a standardisation aspect would give a reduction in the number of parts per aircraft. From an examination of handed fittings it seems probable that the increase in weight resulting from the use of a single fitting would be negligible.

There has been a demand by the material manufacturers for a standardisation of extruded and rolled sections. Large aircraft manufacturers have their own standard sections and parts, which means that the material suppliers must design special dies

and rolls to produce an uneconomic quantity of material. The strongest arguments for standardisation of aircraft material and parts are that:

(1) Increase of production will result.
(2) The number of tools required will be considerably reduced.
(3) The assembly and servicing personnel will become specialists.
(4) Effort spent in wasteful competition between manufacturers will be co-ordinated and concentrated.
(5) The repair and spare part systems will be simplified.
(6) The number of detail drawings required per aircraft will be reduced.

Aircraft Drawings and Limits

Many problems which concern aircraft manufacturers and sub-contractors are in the main attributable to current drawing office practice and there is little doubt that this aspect of the subject is of primary importance. As a rule, the parent contractor readily adjusts his shop methods to suit design requirements, irrespective of whether the drawings give adequate information. The position of the sub-contractor is different, however, as he may be inexperienced in aircraft practice, but may be a specialist in some other branch of industry and consequently able to adopt new or improved methods of manufacture. It is, therefore, proposed to examine D.O. practice and the associated problems from the broadest point of view.

In the past the aircraft drawing office has relied to a large extent on shop practice. Consequently, drawings bear insufficient information for sub-contract work. There is also a tendency to dimension to only two places of decimals and to the nearest minute of an angle. In many cases the problem of putting limits on drawings to secure interchangeability is evaded or not understood. Before the expansion of the aircraft industry it had been the practice to pass the drawings to a tool drawing office for checking and development, prior to jig and tool production being commenced. This checking is now omitted owing to the urgent demand for small tools, which are made in a great many instances direct from aircraft drawings, not always suitable for tool production. The systematic checking of drawings is seldom carried out and they are rushed through the print room and out to sub-contractors, where innumerable shop queries begin. In other words, the shops check the draughtsman's work.

For making laborious calculations the use of calculating machines in drawing offices has been found extremely useful. Dimensions which normally would have been worked out to the first or second decimal place are by this means carried to five decimal places. In order that sub-contracted parts should fit without adjustment, clearances are essential, as also is the manufacture to the limits prescribed by the drawing. The range of limit depends entirely on the clearances provided. It is found, however, that the clearances provided on aircraft drawings do not take into account the tolerances of the mating parts. Take the case of a 0.5 ± 0.010 male fitting which mates with a 0.5 ± 0.010 female fitting. The limits of ± 0.010 will result in an interference of 0.020 in the worst possible cases, that is, with a maximum male and a minimum female fitting. Careful consideration of limits and clearance, together with co-ordinate dimensioning from a datum hole or point, is fundamental to the securing of interchangeability.

It is customary to prepare interchangeability data sheets for the various components of an aircraft, the particulars of main attachment joints clearances being shown for each component. In practice, however, interchangeability data sheets are not comprehensive enough. The result of cumulative tolerances given on the detail parts is to invalidate the dimensions laid down by the data sheets. It is the usual practice for drawing office staffs to be divided into groups of specialists. For instance, one section deals with electrical systems, and other sections deal with petrol and oil installations, fuselage or wings. To achieve the requisite degree of interchangeability for production and service requirements, co-operation between the specialists is necessary. The more progressive firms attach production engineers to the D.O. in order to secure the necessary co-ordination. If this practice were more general, greater progress would be made in aircraft drawings.

As a rule, there appears to be no difference to definite system of limits. The Newall system with its two classes of holes "A" and "B" and its three classes of running fits "X," "Y" and "Z" appears to be favoured over the B.S.I. system. It is considered that the "B" fit hole, which is a common standard with the leading aircraft contractors, is used indiscriminately by aircraft draughtsmen. It is used on parts which may just as well have clearance holes in the region of + 0.002 inch to + 0.004 inch

Also it is found that the bolts to be inserted in the " B " fit holes have minus tolerances on the bolt diameters in the region of 0.005 inch. Where fitted bolts are required it is usual for the drawing office to specify " X " fit bolts with a " B " fit hole, or, if a tighter fit is required, " Y " fit bolts with an " A " fit hole.

The use of clearance holes to some definite system of limits, such as the B.S.I. system, on unstressed detail parts would greatly facilitate detail interchangeability, and replace the various classes of clearance holes now existing. In the B.S.I. system there are four classes of holes, B, U, V, W, and it is possible to use fourteen classes of shafts with each hole, the shafts F, E, D, C, B, K, L, P, M, Q, R, S, T, T, ranging from drive fits to clearance fits. The limits on the holes B, U, V, W are all positive, i.e., larger than nominal diameter. The class of fit required between the hole and the shaft is designated UF, WD, or WC. Adoption of a recognised limit system would facilitate the supply of drills, reamers and checking gauges, which are essential if a limit system is to be operated efficiently. To-day the position is that special reamers, gauges and other equipment have to be made for specific purposes. In short, it is felt very strongly that basically perfect drawings would alleviate some 80% of the principal difficulties with which aircraft sub-contractors have to contend.

Methods of Ensuring Interchangeability

Theoretically, interchangeability of parts can be achieved by working to drawings which carry correct tolerances. To ensure that parts so made fall within the limits specified on the drawings, workshop interchangeability media must be provided. For aircraft work this equipment can be classified as under:

(*a*) Jig References
(*b*) Jigs and Assembly Fixtures
(*c*) Gauges
(*d*) Standard Parts

It is proposed to discuss each of the above items separately to indicate their particular application to aircraft.

Jig References

A jig reference can be defined as a structure of rigid construction used for the purpose of standardising jigs. Normally, when such a reference is used in this way, a subsequent check on the component is unnecessary, the accuracy of the jig being the governing factor. An ideal form of jig reference would be a rigid structure identical in every respect with the component to be jigged. Such a reference would control all the interchangeability features of the component by accurately standardising the assembly jigs.

Unfortunately, experience shows that the difficulties of handling and flexibility are such that the use of such references is impracticable. Before a jig is finally dowelled, the jig reference must be offered up two or three times, and with those of the larger type, hoisting tackle must be provided. In such cases the weight of the reference causes deflection of the jig support, with consequent inaccuracies. To a certain extent inaccuracies due to flexibility in a large jig reference can be offset by the use of numerous levelling pads. The references are offered to the jig, jacked into position and levelled and the jig locations set to the reference. Better results, however, are obtained by using local jig references representing a nest of attachment joints, such as the root end joints of a wing. If this method is used direct measurements are made with extended internal micrometers to set the relative positions of the references on the jig.

A local jig reference scheme as outlined above possesses the advantage that each reference can be mated with its counterpart reference. Therefore, as they both represent the joints of mating components, interchangeability is ensured before production is commenced on the components. For example, a jig reference representing the attachment points of the main-plane centre-section can be mated with a jig reference representing the attachment points of the outer wing. Discrepancies, which occur even with the best of jigging, are obviated by this method. The importance of mating jig references with their counterparts must be strongly emphasised, especially when the aircraft is extensively sub-contracted.

Principles of Reference Design

In designing and limiting jig references for large aircraft, the following basic principle has been adopted. The jig reference represents the component in its worst possible

case : in the case of a male joint, the male fitting on the reference should be made to the top limit of the component male fitting ; conversely, in the case of a female joint, the female fitting on the jig reference should be made to the bottom limit of the component female fitting. Toolmakers' tolerances on the jig reference fittings should fall within the limits quoted on the component fittings so that interference fits are impossible. In working to this principle the tolerances are given in the direction which is least dangerous. Bilateral tolerances should be given on the pin-centre dimensions between jig reference blocks, it being equally dangerous in both directions in this case.

Whatever limit is accepted on the first jig reference the counterpart reference is made from it so that complete matching is achieved.

Even with local jig references about 4 feet square, considerable difficulty has been experienced in designing a structure both rigid and light. One satisfactory type was constructed of M.S. plate. The weight of such a reference was found to be approximately one quarter of the weight of a similar reference made from a Meehanite casting, whilst the deflection under a 50 lb. load on one end was only 0.005 inch.

Light jig references permit the toolmaker to get much finer "feel" when setting the assembly jigs, while handling is made much easier. An extension of the jig-reference system is advocated in preference to gauging, especially with sub-contract work. It is the only practicable way of ensuring jig standardisation, and simplifies jig building by inexperienced sub-contractors.

Jigs and Assembly Fixtures

The primary purpose of a jig or assembly fixture is to facilitate assembly and control the interchangeability features of the component or part. Mass production cannot be achieved by increasing the number of jigs, but rather by decreasing the necessity for jigging by intelligent design.

One of the bottlenecks of aircraft production to-day is the lack of tool-making facilities. The permanent accuracy of jigs is of paramount importance if interchangeability of components and parts is to be maintained. The major proportion of large assembly jigs is made of structural steel sections or castings grouted into a concrete floor, the location blocks for the fittings being bolted and dowelled to the structure. Obviously, the accuracy of any jig is dependent on its foundation and pillar stiffness. This point is often neglected, with the result that additional bracing and tie-rods are added at a later stage to overcome distortion caused by riveting and assembly strains. It is suggested that experimental jigs made with concrete pillars mounted integrally with a reinforced concrete foundation would prove as rigid as some of the present type and be less liable to distortion. This would only mean that the concrete foundation of the jig would be extended to form supports or pillars for the location blocks, which could be mounted on a "picture frame" grouted to the pillar. In other branches of engineering it has been the practice to mount surface tables and horizontal engines on concrete and brick pillars.

Normally, in jig design too little attention is paid to the method of aligning and setting jigs. It is often considered to be sufficient to provide a jig drawing and to leave the tool room to devise ways and means of setting the jigs. It is suggested that, as more than one assembly jig is usually required, the first and fundamental objects to design are the references and jig-bored bars. The jig design is based upon this equipment, which, in effect, is a master component. It is also strongly recommended that large assembly jigs should be split into small sub-assemblies. Each sub-assembly should be capable of being set on a surface table to the appropriate jig reference. This method reduces considerably the time spent in setting location blocks from arbritrary datum lines, piano wires and straight-edges in the shop.

When the jig sub-assemblies have been checked as a unit against the jig reference they are mounted on the jig pillars. To ensure the correct relationship of each sub-assembly fine-adjusting studs are necessary between the pillar and the unit. When the correct position of each sub-assembly has been determined, the units are dowelled and finally secured by Cerromatrix, which is poured in between the two parts. The method of filing and scraping rough jig pillars to bed down a series of location blocks is laborious and slow.

Practical experience has shown that the tolerances on detail sockets and hinges are often neglected in jig design. When the jigs are completed and the parts are offered up prior to the building operation, interference usually occurs. Production limits on detail sockets, for example, may be $\pm$ 0.010 inch. Obviously, the inspection department must accept these parts as they are to drawing, although a male socket may

be + 0.010 inch and a female socket − 0.010 inch. This means, therefore, that the assembly jig must be capable of accepting sockets in their worst possible case.

It is improbable that all sockets will be on the worst possible limit, but the toolmaker's tolerance on the jig detail should fall outside the limits on the detail socket. The consideration of primary importance is that the toolmaker's limits on the jig reference sockets do not cause interference when the jig references are mated together, and the secondary consideration is that the jig locations will accept the jig references.

If the component sockets are made to the other extreme limits resulting in clearances when offered up to the jig, it is recommended that loose shims be attached to the jigs in order to centralise the socket. These shims can also be adapted to facilitate withdrawal of the finished component from the jig.

Setting Assembly Jigs

The increase in size of aircraft components has emphasised the inadequacy of measuring equipment for long distances. Equipment used in setting large assembly jigs can be enumerated as follows :

(1) Direct measurement.
(2) Jig references.
(3) Jig-bored bars.
(4) Taylor-Hobson alignment telescope.
(5) Surveyor's dumpy level.

By direct measurement is meant the use of standard measuring equipment such as verniers, internal micrometers, straight-edges and slips. To set a large assembly jig by this method is a tedious process, and cannot be relied upon to give interchangeability. The dimensions are measured separately, with the result that cumulative errors occur. Simultaneous checking of all points by means of jig references is a much better method and gives greater accuracy. Another disadvantage when using direct measurement is the need for creating as a reference for all measurements an arbitrary datum line which must be produced physically by straight-edges or plumb lines.

As previously stated, as much work as possible should be carried out in the toolroom, where the facilities for accurate work are infinitely better than in the shop. Direct measurement can be said to be the average result of many measurements. There is always an indeterminate quantity present due to the tolerances in holes, gaps, and other apertures. Furthermore, the human element is a variable factor in making this type of check. A jig drawing will give a dimension between two location blocks from centre line to centre line. These points do not exist physically, so that parallel strips, Johansson slips, or ground test bars must be used to give measuring points for the measuring equipment. Diameters of test bars or widths of slots have to be added or subtracted from the actual measurement to arrive at the drawing dimension. With location blocks at varying angles special equipment must be made to facilitate checking, and each piece of equipment obviously must have toolmaker's tolerances for manufacture.

Checking by Micrometer and Level

In cases where adequate clearances exist between mating components, direct measurement may suffice to produce interchangeability, but where small clearances only are permissible this form of checking is not desirable. Two very useful items of equipment for checking jigs are the Johansson internal micrometer and the Starrett precision engineer's level. The micrometer set contains a micrometer head, six extension rods, one each 1 inch, 2 inch, 4 inch, 8 inch, two 16 inch and one end piece. The normal range of 3 inch to 51 inch can be extended by the use of the 16 inch extension pieces. Over lengths of 15 feet to 30 feet the equipment is too flexible. This disadvantage, however, can be overcome by using a sensitive level on levelling pads attached to the extension pieces. The Starrett precision level consists of a robust casting, which is insulated from the effects of handling by a top plate of non-conductive material. It is 15 inches in length, 3 inches in height, and 1½ inches in width. The graduated dial is divided so that one division reads 0.0005 inch per foot. The use of jig references for standardising jigs has already been discussed.

Final Setting

To set an assembly jig finally, the distances between the local jig references must be determined. This is accomplished by the internal micrometer already mentioned, the measurements being taken from datum faces on the references. Flexibility in measuring equipment over distances of 3 feet is a serious problem when setting large

jigs. It may be argued that it is not essential for large jigs to be so accurate, but it has been found that spars and sub-assemblies have to be reamed in the final assembly jig because of variations between the sub-assembly and final-assembly jigs.

A partial solution to this problem is provided by jig-bored bars and links, the bars being made of flat ground steel strip 2½ inches by ⅝ inch by 60 inches. The bars are arranged to link the various location blocks on the jig, holes being jig-bored at suitable points. With the aid of blocks the bars are always kept horizontal so that the precision level can be used. The ordinary inclinometer is unsuitable for jig work. These bars are relatively light and rigid and permit a fairly sensitive " feel." Another advantage is that a pair of bars can be jig-bored together, so eliminating possible errors. One bar can be used for the male jig and the other for the female jig.

Straight-Edges

The flexibility of straight-edges has been discussed mathematically by F. H. Rolt in his book *Gauges and Fine Measurement*. It is shown that for a normal straight-edge of 72 inches by 3 inches by ⅜ inch the deflection in the centre when supported at the ends is 0.0045 inch. When supported near the centre the deflection at the ends due to its own weight is in the region of 0.0025 inch. By supporting a straight-edge on two points separated by a distance apart equal to 0.0554 of the length of the straight-edge it is proved mathematically that the deflection of a straight-edge can be reduced to a very small amount (0.00009 inch).

Experiments carried out on straight-edges confirm these results. It appears, therefore, that the ordinary straight-edge which is used extensively in jig building is in itself a very poor foundation for accurate work. The principle laid down by Sir Joseph Whitworth still holds good, " The basis of all measurement is an accurate surface plate."

The problem is, therefore, to extend the accuracy of a surface plate to serve for long distances. It is suggested that cast straight-edges of parabolic shape 60 inches long by 2 inches in width should be made on a production scale to N.P.L. Standards. Their accuracy may be obtained either from a reference surface plate or by working three straight-edges together in the same manner as small surface plates. Each straight-edge should be jig-bored at points equal to 0.554 of its length, that is, at the points of support calculated to give minimum deflection. A series of jig-bored holes should be interposed between these points, and suitable levelling pads parallel to the lower surface attached to the top surface so that a sensitive level can be used.

Once such standards were obtained, the major difficulty in setting large jigs would disappear, as faithful reproductions of a flat surface would be available and guaranteed jig-bored centres. The method adopted to build a large jig would be as follows:

Adjustable datum points would be set in the base of the jig at intervals corresponding to the jig-bored cetnres on the straight-edge. By using a precision level and straight-edge, the datum points would be adjusted to form a level surface in all directions. Furthermore, the distances between datum points would be to close limits.

The object to be aimed at is the creation of a surface table to which all dimensions can be referred, this surface table being, however, a series of points linked together by straight-edges. By the use of suitable jig-bored links carrying levelling blocks, the straight-edges can be used in the same manner as a sine-bar for setting out angular dimensions, so obviating one of the commonest sources of error in jig building. The most important point is that the problem of measuring long intervals has been reduced to a series of short distances set to a definite and rigid standard of length.

Optical Equipment

Equipment such as the Taylor-Hobson alignment telescope and collimator simplifies the alignment of two ends of a large jig, and furnishes a ready means of creating an optical datum line throughout the jig. Briefly, the scheme is to mount the telescope and collimator on jig references or posts at opposite ends of the jig, the collimator having two graticules, one showing angular displacement whilst the other shows vertical and lateral displacement. This instrument makes it possible to set the two ends of a jig in a vertical and lateral relationship. The distance between the two ends, however, has still to be determined. In practice, the mounting and setting of the instruments on the jig references or supports needs considerable care, whilst physical methods of checking give a greater degree of confidence than optical methods. It is understood that efforts are being made to fix the collimator on brackets that can be adjusted within prescribed limits.

A surveyor's dumpy-level or transit can be used in a similar manner as the alignment telescope, the dumpy-level being set up in the shop and focused on a graticule mounted on the jig. In this way a number of points on the jig can be levelled. In practice, however, the instrument cannot be considered accurate over distances of 20 feet to 30 feet and it possesses the same disadvantage as the alignment telescope, in that it does not provide a means of ensuring the relative position apart of the two ends of the jig.

Other methods of levelling are the use of water tubes with a connecting piece, and mercury troughs with micrometer heads attached, the reading at the point of contact being determined electrically. The use of taut piano wire for determining plan alignment is sometimes used, the point of contact again being indicated by electrical means.

Interchangeability Gauges

A gauge can be defined as a piece of equipment so designed and dimensioned that it will accept parts or components falling within the limits prescribed by the drawing. The application of interchangeability gauges to aircraft is usually confined to moving parts such as ailerons, rudders or flaps, where adequate clearance exists between the mating parts. It is applied to the component when completed, as distinct from a jig reference which is applied to the jig. An interchangeability gauge possesses the advantage that it can detect errors in manufacture due to such causes as distortion by fabric covering or riveting strain. As such, it is primarily an aid to inspection, and it only shows that a job is right or wrong at the completion of the work. It does not help the sub-contractor or user to determine the accuracy of his jigs before work is commenced.

With the increase in size of components, the problem of designing rigid yet light gauges has become increasingly difficult. Previously on small aircraft, a simple tube with hinge locations and profile plates would suffice to control the interchangeability features of small components. For overcoming the flexibility of large gauges the method adopted is to mount them as rigid checking fixtures in the floor of the shop. This presumes, of course, that the component is light enough to be offered up to the gauge. Ailerons, elevators, fins and rudders are readily gauged in this manner. The provision of levelling pads on a gauge permits it to be aligned correctly at the works of a sub-contractor by means of a sensitive level.

Gauging such points as the aileron gap in the main plane requires careful consideration. The component is too heavy to offer to the gauge, whilst the design of a rigid and light gauge suitable for offering up to the component is very difficult. Several types of gauges for this purpose are used, usually in the form of tubes arranged in a triangular disposition around the hinge locations. The manufacture of gauges for this purpose is a field for development work, the criterion being that they must be light and easy to apply, as otherwise they will find a resting place in the dusty confines of some remote store.

Interchangeability Data Sheets

A series of short gauges may be used, but there is the danger of cumulative errors when all the interchangeability features are not checked simultaneously. With regard to the dimensioning and limiting of interchangeability gauges, the drawing office usually prepare interchangeability data sheets. These sheets give information concerning the overall dimensions, clearances between mating components, hinge centres, together with the limits permissible in each case. The dimensioning of the data sheets is usually based on a datum hinge or point, all key dimensions being referred to this datum, and not from one another. Gauges are designed from such data sheets and not from the aircraft detail drawings. The gauge should be dimensioned to accept a component or part within drawing limits.

Consider the case of aileron hinges, with a female hinge on the aircraft structure and a male hinge on the aileron. By drawing the envelope of each hinge in all its possible positions caused by the tolerances on the detail hinge and the tolerances on centres between the hinges, the inner figure obtained for the female hinge becomes the outer profile of the male gauge for checking the female hinge. Conversely, the outer figure of the male hinge becomes the inside profile of the female gauge checking the male hinge.

A point often overlooked is that when the datum hinge is on the clearance limit, that is, the top limit for a female hinge and the lower limit for a male hinge,

the component can slide to and fro in the gauge to the extent of the detail tolerance. It is, therefore, recommended that the gauge should have loose slips attached to the datum hinge in order to centralise the component. Obviously, gauges are designed to control the component in the most dangerous direction. If the component falls in the direction which gives the most clearance, loose slip gauges can be attached to the gauge to prevent excessive clearance.

Toolmakers' Tolerances

Toolmakers' tolerances should be such that the full limits permitted by the component drawings are observed. There may be cases, however, where the clearance between mating components is small so that the toolmakers' limits must fall within the limits quoted on the component drawing. Generally speaking, the toolmakers' tolerances are 10% of the work tolerance, a tolerance of $\pm$ 0.001 per foot being allowed; on centre dimensions over 5 feet and up to 15 feet a standard tolerance of $\pm$ 0.005 is allowed.

Standard parts are used where it is not practicable to employ a jig reference or gauge, and are intended primarily for obtaining interchangeability of detail parts or fairings. They are used to check the production tools, or as a comparative check against subsequent production parts.

Slight variations due to manufacturing tolerances do occur with this form of control but if suitable clearances are provided on assembly, these variations are absorbed.

Three fundamental factors necessary for ensuring detail interchangeability should be reiterated :

(1) The correct use of limits and clearances on aircraft drawings.

(2) The tools used for the manufacture of the detail parts must be accurate, and where more than one particular tool is in existence all must be identical.

(3) The inspection department must work to drawing.

There are two possible ways of operating a standard part system. One is to produce the component from the aircraft drawings, strip it down and use the detail parts as the standard for subsequent manufacture. In practice this means that any variations from drawing are accepted and standardised as far as possible. One great difficulty is that the standard parts are subject to drawing alterations, and the correction of the standard must be carried out to suit the latest issue of the drawing. Consequently the production of tools is held up pending the rectification of the standard part.

It is suggested that the number of corrections due to re-design of parts or faulty draughtsmanship can be considerably reduced by the following procedure. The first step is the preparation of master drawings suitable for tool production from the aircraft drawing ; or preferably the aircraft drawings should be made suitable for the production staff in such a way that tools can be made directly from them as previously suggested. Limits based on the permissible clearances between the mating parts and the fit of bolts or tie-rods should be indicated by the master drawings, which become the standard for tool production, and also the basis for tool inspection. Parts made with the tools are then subjected to a tool try-out to check any arithmetical errors that may have occurred in the preparation of the drawings. When this has been successfully carried out, the parts used can be adopted as the standard for subsequent production and, furthermore, there is a record of each part in the master drawings.

When alterations caused by the inevitable additions and modifications have to be incorporated in the standard parts, the master drawing should be corrected first and distributed. Rectification of the standard part and the correction of existing tools can then be achieved simultaneously by using the master drawing, the tools being finally checked against the corrected standard part.

Cowlings and Fairings

A physical check on a tool, as obtained with a standard part, where all the features of the tool are checked together is much better than using height gauges, verniers, Johansson slips, where each dimension is checked separately. The standard part scheme is particularly applicable to cowling panels and fairings, where it is very difficult to give dimensions which are suitable for production.

It may be remarked here that the interchangeability of cowlings and fairings is one of the most difficult problems on aircraft. The usual practice is to construct a full-scale mock-up or jig which represents the aircraft structure. From this mock-up a set of steel cowling panels is made, suitably braced to give the requisite stiffness. Positions

of fasteners are determined from the mock-up, the edge profile of the master panels being adjusted to give even gaps between adjacent panels.

The standardised panels can then be used to :

(1) Reproduce the full-scale mock-up for sub-contract work.

(2) To construct jigs for producing the individual panels.

(3) To position the cowling fasteners correctly on the aircraft structure.

The steel panel fasteners should be made without tolerance as they are, in effect, jig references.

A cowling is usually supported by a former structure built up on the basic aircraft structure. This former structure is invariably very flimsy and flexible, making the accurate positioning of the panel attachment points difficult. Pre-location of the attachment points on the formers by sub-assembly jigging does not ensure the correct relative position when the former structure is attached to the aircraft structure. It has been found necessary to carry out adjustment of fastener positions by the steel master panels during the final assembly.

Another source of trouble with cowlings is the variation in rigging of the components over which the cowling passes. The rigging of components on two aircraft on the production line may be slightly different, even though they are carefully jigged. Consequently, the cowling panels covering the gaps between the components do not fair with their adjustment panels. In the design of cowling, consideration should be given to the following :

(1) Each component should have its cowling panels integral with it. That is, the practice of attaching the front of a cowling panel to one component and the rear end to the adjoining component should be avoided wherever possible.

(2) Adequate clearance should be provided between adjacent panels. The gap can be covered by a joggled strip attached to one panel.

(3) The former structure should be as simple and rigid as possible.

(4) Cowling features should be mounted on brackets capable of adjustment. The fastener itself should have ample clearance between the male and female positions.

The essential features of a really successful fastener are robust design, quick action, ease of inspection, and ample clearance for interchangeability.

It seems possible that with the increased speed of modern aircraft, the security of the panels will only be achieved by a screw-type fastener and not by the quick-release spring type used at present.

(5) The number of panels should be kept to a minimum, single large panels being preferred to a number of small panels.

This also simplifies tooling by reducing the number of dies required for drop-hammer work.

To ensure the fit of undercarriage doors on final assembly, it is necessary to wait for the undercarriage retraction tests, and valuable time is lost at a vital stage in manufacture whilst the doors are adjusted. Obviously, the doors can only be closed when the undercarriage is retracted. This difficulty has been overcome by making master undercarriage doors with suitable cutaways in them to clear the undercarriage struts when they are in the down position.

These master doors are offered up to the aircraft and the gaps and hinge positions adjusted at an early stage. The production doors are then assembled, and checked in the closed position when the undercarriage retraction tests are carried out. In this way considerable time can be saved at the most critical period.

Conclusion

The purpose of this article is to put on record some of the difficulties encountered when dealing with the interchangeability of large aircraft which have been extensively sub-contracted. The main points requiring consideration are summarised below :

Drawing limits should be standardised, as this would reduce production costs and also simplify the supply and maintenance of shop gauges.

Standardisation of parts should be carried out on a wider scale under some co-ordinating authority.

Sub-contractors should be allowed to specialise on one component only, and not devote their energies to producing as many components for as many aircraft as possible, with the consequent disorganisation of stores and production systems.

Improved equipment for setting large assembly jigs is required.

Detail interchangeability must be planned at the commencement of design, by

master drawings and standard parts. To this end drawing alterations must be kept to a minimum.

Parent firms should create a special department to deal with interchangeability problems.

Toolmaking facilities should be extended to cope with the increased requirements of production.

STORES AND MATERIALS CONTROL

By FRANCIS W. COOK

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EFFICIENT provisioning and storage of raw materials or finished parts is an integral part of production planning.

Too often in the past, the Stores and Materials Control has been regarded as the Cinderella of the plant, but planning engineers are rapidly realising that without well-organised materials control, production can and does suffer.

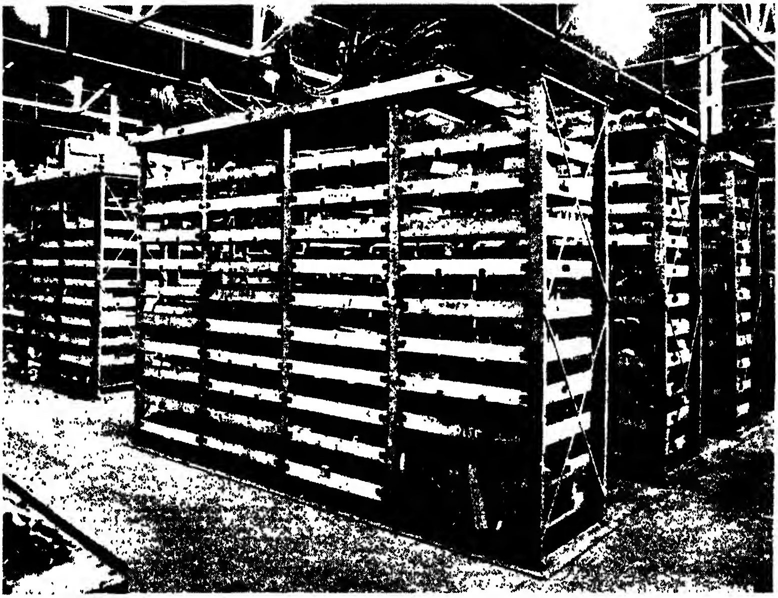


Fig. 11.—*Tray rack.*

Ratio of Materials Income to Production Flow

When a new plant is being organised, Stores and Materials Control planning is simplified if it is in the hands of an expert. This planning should never be left to the whims of a storekeeper who may too often be ill-chosen or little better than a labourer. Such a man may know how to run his stores with the minimum of trouble to himself, but he cannot, and should not, be expected to appreciate the ratio of materials control to the production flow.

Planning to Overcome Shortages

Due consideration must be given to the problems of the storekeeper, but always in the closest conjunction with the Production Manager's requirements. Whilst most

storekeepers believe they have evolved the perfect system, shortages have been the Production Manager's greatest worry, and the fool-proof Stores and Materials Control system which will completely eliminate this worry has yet to be conceived.

There is a tendency for Stores Control and Production to continue to work as two distinct watertight compartments, instead of being welded into one harmonious whole. In so far as the organisation falls short of this desideratum, there will be restrictions on the flow of materials and parts, with correspondingly limited production.

The most important function of Stores and Materials Control is to prevent shortages, and this will only be done if the system is correct, the stores equipment efficient, and if the storekeeper holds his position by virtue of his knowledge of Stores and Materials Control.

Fixing Maximum and Minimum Stocks

The Purchasing Department cannot function correctly if Stores and Materials Control is out of date or run without a clear system of minimum and maximum requirements. It is of no use to blame the Purchasing Department for hold-ups in production due to shortages, if Stores and Materials Control has not in good time advised the Purchasing Manager of an approaching minimum in stock.

Fig. 12.—Two-tier sheet racks.

Allowing for Extended Delivery Periods

Purchasing Departments are too often accused of incompetence or negligence when Stores and Materials Control was really at fault. There are delivery periods to almost every item of raw material and sub-contracted part, and unless these periods are calculated in Stores and Materials Control, shortages will continue to be the bottleneck which has proved to be production's greatest setback.

Use of Steel Equipment

The methods of storage are as diverse as the articles required to be stored, and it is not proposed to detail the more popular methods except in so far as it is necessary to dispel a few illusions.

This article deals only with steel equipment, and it is assumed that the use of timber will be avoided wherever possible. At this late stage in the career of stores equipment it is quite unnecessary to press the claims of steel to the exclusion of timber. This educational work has been very well carried out by the equipment manufacturers themselves.

Shelving

In recent years it has been the practice of stores equipment manufacturers to stress the importance of up-and-down adjustability in steel shelving; and for the storage of quantities of medium and large materials adjustability of this type is advantageous But for the storage of smaller parts, up-and-down adjustability is not practical, for the good reason that perhaps only 40% of storekeepers will take the trouble to empty the shelves, take out nuts and bolts, lift or drop the shelves, and safely replace the nuts and bolts. An examination of adjustable steel shelving in stores at any moment will probably show that at least $33\frac{1}{3}$% of the storage space is not being used to advantage.

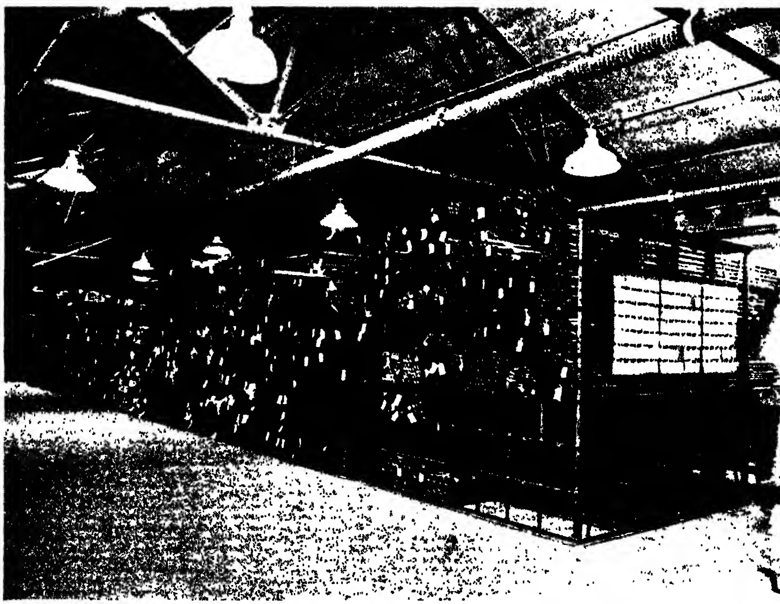


Fig. 13.—*Pigeon hole rack.*

Removable Dividers and Fronts

Rather should stores be equipped with steel shelving having the *shelves* perforated at back and front with removable dividers provided. By this means stores space is well utilised. The removal and replacement of these dividers is a matter of seconds, and section by section any one shelf can be filled to capacity. Removable fronts from 2 inches high upwards are made by most equipment manufacturers. These can be fitted to as many, or as few, shelves as is necessary, and these removable fronts will be found to be of inestimable value in the storage of small parts.

Two-Faced Stacks

When space for shelving is being laid out on the floor plan, it is as well to use as many double-sided or double-faced stacks as possible. The reason for this is perhaps obvious—stacks built in this manner use a common back sheet and a sheet of steel is saved in every two bays. If at a later date it becomes necessary to change to single-sided or single-faced units, it is a simple matter to order extra back sheets from the

equipment manufacturers. This also applies to runs of shelving: runs should be as long as possible, leaving ample gangway space; every two bays linked together require only a common side sheet. Here again, if it is decided to move the shelving around, the equipment manufacturers will supply extra side sheets.

Small Drawers

To store small parts such as nuts, bolts in boxes, screws, etc., use small drawers. A useful, easily handled size is between 3 inches and 5 inches wide by approximately 3 inches to 4 inches high, and up to 12 inches in depth, with either adjustable or fixed dividers running the length of the drawer. By this means an infinite variety of small parts can be stored, and valuable store space will be saved. These boxes should be stored on shelves, thus enabling the shelving units to be used for larger parts from time to time.

Tray Racks for Assemblies

The introduction of trays for storage purposes is not new, but it has been found that they are the most suitable medium for storing assemblies or sets of dissimilar

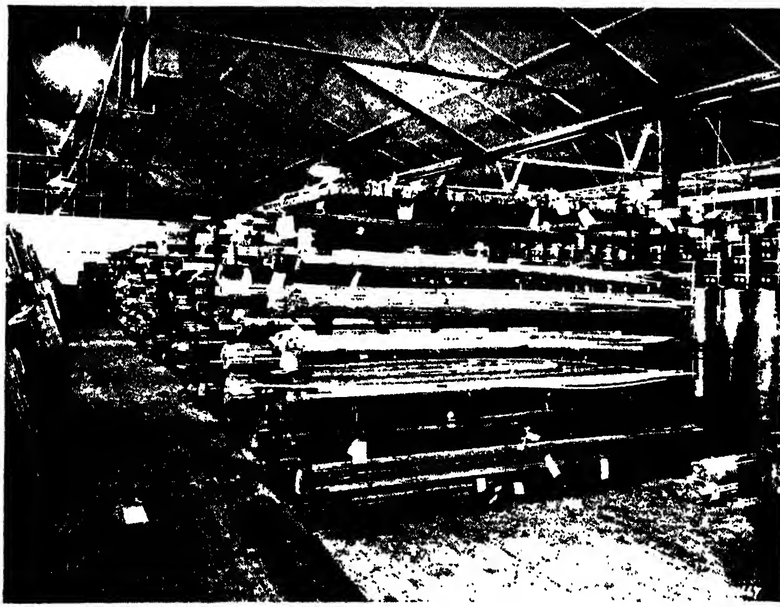


Fig. 14.—*Horizontal rod, bar and tube storage racks.*

parts. The trays are made of wood or steel, according to the amount of weight they are expected to carry. These trays are held in metal racks, to the uprights of which are attached a series of angle runners. It is a simple operation to slide the trays in and out, and an indication can be marked on the front of the tray to show the contents. If the class of goods handled is constant, it is of course possible to subdivide the trays to suit the various components carried. It will be appreciated that as these assemblies are put up in machine sets of anything from 10 to 60 sets per tray, and the racks are capable of holding a month's supply or more, all shortages are thrown up automatically at least a month ahead of the shop requirements. It also means that an immediate issue can be made to the shop at any time without waiting for the assembly to be made up. This saves operators' time.

Tray racks can, of course, be used in static storage, but in the majority of cases they will be found to be uneconomical, as unless sufficient stocks are carried to fill complete trays, a large space would be empty. A number of aircraft manufacturers are using

the Tray Rack method for pre-staging or kit marshalling, but to obtain full benefit from the trays a proper racking system must be introduced as outlined above.

Box Racks

These are racks built in much the same way as Tray Racks, but using smaller boxes instead of trays. Where it is necessary to store small parts, boxes may be more suitable than trays. Boxes are from 12 inches to 18 inches long; 9 inches to 14 inches wide; and between 3 inches and 6 inches high. The interiors of the boxes can be subdivided by means of fixed or removable dividers.

Where only small parts are to be stored, the boxes are more easily handled than trays, can be more readily removed and/or replaced, and although they need more frequent refilling for sub-assembly work than do trays, it is possible to keep an easier check on their contents during production flow.

Sheet Racks

Should sheet be stored vertically or horizontally? Both schools of thought are right if they are talking about different materials. Light alloy sheets are better stored vertically; and if the rack is of timber or, even better, of steel with timber facings, there is less likelihood of surface scoring taking place than is the case where non-ferrous sheet is stored horizontally. The pigeon-hole type of rack for storage of alloy sheets is not to be recommended, for the sliding of the sheets one against another does increase the possibility of surface scoring.

Sheet Oiling Machines

Perhaps the only satisfactory way of applying an equal anti-corrosion film to alloy sheets is a sheet-oiling machine, of the type produced by Hedleys Limited. It can be used for most preventives on ferrous sheets; and for the application of drawing grease. Colour can also be applied to the whole sheet, identifying the grade, and making the sorting of scrap a simple task.

Tree Racks for Sheet Metal

The equipment to be definitely recommended is the tree rack, i.e., racks made from steel angles welded to verticals, the arms or branches being faced with 1 inch or 2 inches thick timber. These can be made for one tier or two tiers storage, and with the standard set 4 feet or 6 feet apart, 4 feet, 6 feet, or 8 feet long sheets can be stored where they can be readily removed and the stock easily checked.

The storage of steel sheets does not present so much difficulty. Here either a vertical or a horizontal storage rack can be used, a vertical type being the tree rack, as described above, or a rack made up with compartments high enough to take sheets up to at least 4 feet wide, deep enough to take sheets up to 6 feet or 8 feet long. No compartment should be wider than 18 inches, or the first sheets in the compartments may suffer from buckling, caused by the weight imposed on them by the later stored sheets. The horizontal type should be of pigeon-hole design; at least two tiers but not more than three tiers high; each compartment wide and deep enough to take the width and length of the usual sheet, but not higher than 2 feet, or the sheets will become too heavily packed for easy handling.

Rod, Bar and Tube Storage

Given sufficient floor space the pigeon-hole rack is the ideal equipment for rod, bar or tube storage. This rack is made up into compartments which may be all of one size (usually 12 inches to 15 inches square), or in order to take variations in thickness or diameter of material components, may vary from 6 inches to 24 inches square. By this means, material in long lengths can be readily stored and remains easily available. Framework of steel angles or channels, usually 6 feet to 10 feet long by the same distance high, is welded up. Vertical and horizontal carrier bars are welded to this frame to form the pigeon-holes. The frames are then set two or more in depth to accommodate any length of material. Frames should be set up not more than 3 feet apart, thus preventing sag in the material to be stored. This type of rack permits withdrawal of rod, bar or tube from 3 feet to 30 feet in length. Often incorporated in this rack is a compartment or compartments for the storage of off-cuts. When this is done, it is right to sheet over the bottom of one or more of the compartments in order to prevent the off-cuts falling through.

Loads on Rack and Floor

As will be seen, it is necessary to have a floor space twice the length of the material to be stored, in order to load the racks, but the distinct advantage of the pigeon-hole rack is the accessibility of material, the ease of segregation of one section or diameter from another and the vast amount of material which can be stored on relatively small floor area. Racks of the pigeon-hole type have been built that can carry 1,000 tons of material and yet not have any compartment larger than 12 inches square. It is important to calculate the total load per foot run when designing this type of rack; and it is better to err on the side of caution, on account of the possibility of overloading not only the rack, but the floor.

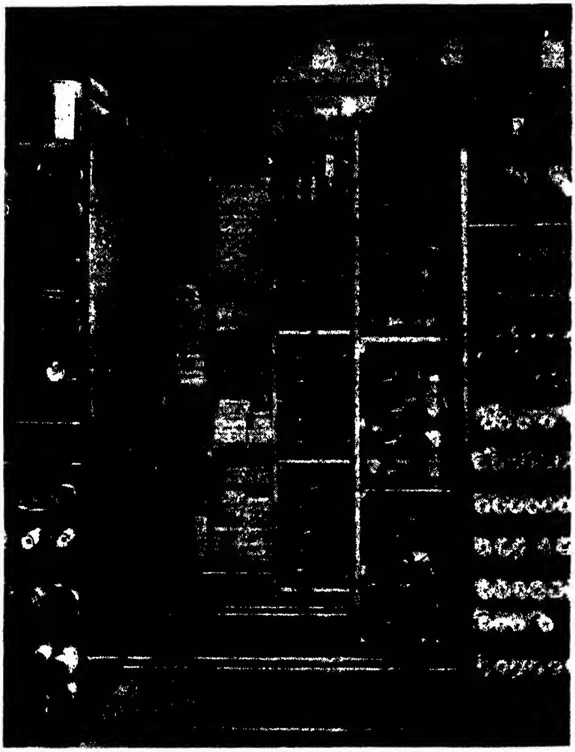


Fig. 15.—Stormor open bins, on ball-bearing rollers.

Limited Floor Space

When floor space is limited, gangway racks may be used, built on the tree principle with carrier bars welded to the verticals. The trees are then built up with distances varying from 3 feet to 5 feet between each, the whole tied together with a top angle and with braces between each tree or standard. Material is placed on the carrier bars. This method will be found to be excellent where extruded sections are to be stored, and is particularly useful for storage of light alloy sections where surface scoring is to be overcome. In this case timber facings should be used, as for the storage of light alloy sheet. With the gangway racks, slings and cranes can be applied to the handling of materials on to the racks.

Uneven Loading

Usually this type of rack is not more than 2 feet 6 inches wide at base for single-sided racks, and not more than 6 feet wide at base on a double-sided rack. This being

so, it is better that provision should be made for floor fixing, usually by rag-bolting or by the well-known floor plugs method. There is a slight tendency amongst store-keepers to load and unload this type of rack unevenly, and unless there is a floor fixing there remains the possibility of topsway.

Horizontal Racks

Lastly there is the horizontal storage rack. This rack enables rod, bar or tube of the medium heavy sections or thicknesses to be stored with a minimum of floor space requirement. The steel angle vertical frame or standard, triangular in formation, is welded up and a series of these tied together as in the gangway rack. One end of the material stands on the floor or on trays; the material rests against the connecting bars, and variations in material sizes or specifications can be separated by a series of arms bolted or welded to the connecting bars. Horizontal racks can be single or double sided, and provision for floor fixing should be made. Equality of loading on each side should be insisted upon in a double-sided rack; the risk of accident is negligible, but it is possible to accommodate particularly heavy loads in this type of rack.

Unit Bins

Here is a method with small parts storage which has stood the test of time; for it is a method as old as stores equipment itself. Unit bins are made up in a number of small compartments, all of one size or in a variety of sizes. Their great advantage is the ease with which units can be added, to build up a complete installation for small parts storage. Usually the units are around 6 feet high, 3 feet wide and 1 foot deep, having flat or dished shelves. They are particularly flexible; for complete rearrangement of a stores lay-out can be made very rapidly. It is not always necessary to empty the unit bins before the rearrangement can be carried out. Considerable weights can be stored in the unit bins, for each row of compartments is stiffened by a steel rod running through their width. These steel rods are threaded and fastened into position by a locking nut.

Fixed Bins

These bins are similar in construction and design to the unit bins, but instead of being flexible units, they are built up in long runs in the same manner as shelving. These bins are particularly suitable for carrying heavy loads of small part or component storage, where it is unlikely that frequent revisions of the stores lay-out will take place. The road and nut fixing to the shelves or compartments does not lend itself to short-term storage, for dismantling and re-erecting is not the simple matter it is when steel shelving is used.

Where a ledge for handling heavy components is required, fixed bins are useful, usually 18 inches or 24 inches deep, with a height of 3 feet from the ground and 12 inches or 18 inches deep above the ledge up to the required total height.

In general practice fixed bins are being superseded by steel shelving.

Some Practical Hints

In closing, the following points may be stressed:—

(*a*) If there is plenty of head-room, build shelving high, and use ladders.

(*b*) Store valuable components in cupboards which can be locked.

(*c*) Make the storekeeper *responsible* for his stores.

(*d*) If standard pieces of equipment will not do for the job, have the equipment designed by an expert.

(*e*) If the equipment can be made in steel, have it made in steel and do not get the carpenter to knock-up something which will "do the job for the time being."

(*f*) A well-equipped, well-organised Stores and Materials Control will go most of all the way towards curing the bottle neck of shortages.

Stormer Economical Storage

Provision of adequate storage space in workshops is essential if material, equipment and tools are to be preserved from damage due to accident or careless handling and yet be available at short notice. On the other hand, the areas devoted to this purpose are not directly productive, and any development which permits economies to be made either by reducing the space required, or by making more efficient use of that so allotted, merits the attention of works engineers.

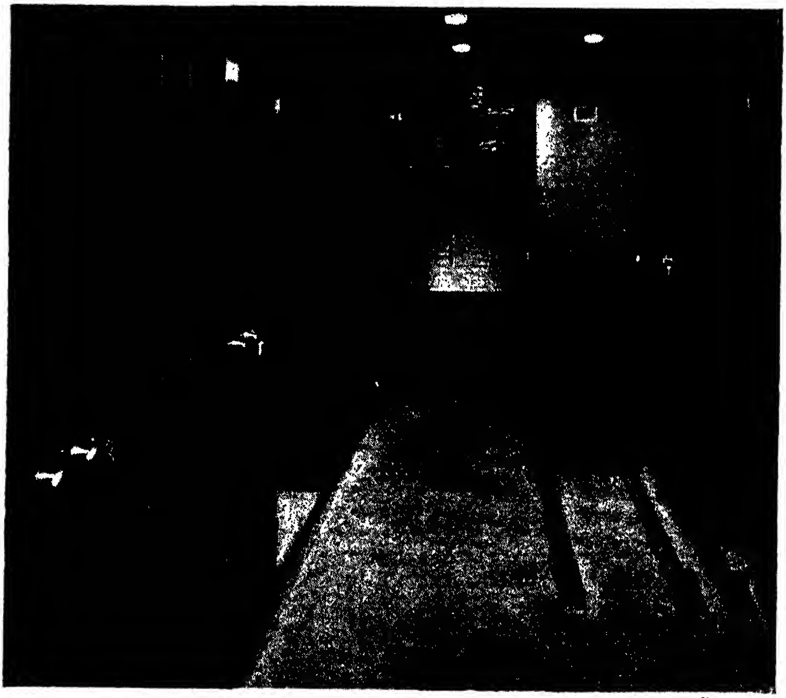


Fig. 16.—*Stormor steel cabinets.*

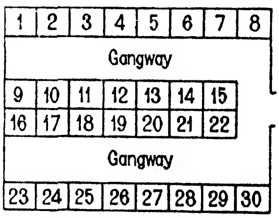


Fig. 17.

A typical store layout making use of fixed racks and bins.

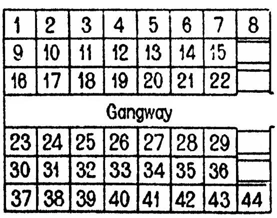


Fig. 18.

The same area equipped with Stormor type mobile storage units.

Use of the Stormor system, as produced by J. Glover & Sons Ltd., of London, S.W.18, it is claimed, increases the amount of storage space in a given area by 40 to 50% by reducing to a minimum that normally occupied by gangways.

The bins or racks are supplied as separate units mounted on ball-bearing wheels which run on rails laid in the store-room floor. Given a triple row of such units, with a single gangway along the front of the foremost row, access can be obtained to any bin, under the Stormor system, by the expedient of leaving a vacant space equal to the width of a single unit in the two front rows. The rear row units may be fixed.

This permits bins in these two rows to be pushed aside on their rails so leaving a way clear to those behind. This method avoids the necessity for a second gangway, which would be needed with three rows of fixed bins.

Stormor units can be made in various sizes to suit individual requirements. Construction is in steel with olive-green enamel finish. It is claimed that an entire row of these units can be moved easily by hand effort only, even when fully loaded. Risk of crushed fingers is avoided by the provision of small rubber buffers, these being fixed to the sides of the units to prevent them from coming into direct contact.

THE QUALITY OF ENGINEERING PRODUCTS

By H. H. JACKSON, M.I.E.I., A.F.R.Ae.S.

THE methods of maintaining the quality of engineering products are naturally varied according to the wide range of components, sub-assemblies, units, etc., that are manufactured, and also according to the tolerances relative to the products in question. A study of these methods, however, shows that many of them have features in common although their evolution and final organisation are the outcome of factory systems which bear only slight comparison. The determination and supervision of the quality of manufactured articles are industrial essentials which take very different forms in the organisations of the various types of engineering works; yet in each case there must exist a co-ordination of personnel capable of supervising the regular output of goods which will reliably fulfil the ultimate service requirements of the specification for the final product. Briefly, then, the " regular passing of reliable goods " is the aim of the quality engineer, or his equivalent.

The Position of the Chief Inspector

By and large, it is the chief inspector who is mainly responsible for the maintenance of the quality of a manufactured product, although the degree of this responsibility depends on his position in relation to the remainder of the executive organisation. Again, the philosophy and outlook of the chief inspector have a definite bearing on the relations between his firm and the customer, Service or consumer. He should be well aware of the limits of the conditions to which his goods will be subjected, and should be able broadly to differentiate between failures due to abnormal service conditions and those due to manufacturing discrepancies. It therefore behoves the chief inspector to work in close collaboration with the design and development departments in such matters as service failures, customers' complaints, etc., in order that he shall not become the mere recipient of modifications the origin or *raison d'être* of which is unknown to him.

Inspection and Works Organisation

It is essential to the harmonious development of any factory organisation that the production and inspection departments shall have a clear mutual recognition of their respective functions. Modern methods of production beget a tendency for the production superintendent to press for the most expedient manufacture possible, so long as the goods or articles will not be rejected by the inspection department. The last clause is sometimes regarded as being of secondary importance by the zealous production man, be he superintendent, rate-fixer, or production control engineer, and the idea may arise that inspection is an obstacle to be overcome, culminating in a veritable battle of wits between the departments concerned. This is a real menace in any engineering firm, and has an evil influence on production output and time of inspection alike, besides engendering an unwholesome competitive spirit to the detriment of the ultimate quality of the product. The decline of pride-in-workmanship due to bonus systems sets many problems in inspection organisations, but the position

should never become so acute that the production man is constantly working on the borderline of reasonable rejection: neither should the inspector be insistent on the maintenance of any sudden improvement over specification requirements, as it may well be due to a dozen variables, which creep into different production batches, and may be impossible to account for. So long as the production staff are concerned with the expedient manufacture of correct quality goods, the inspector will have few worries in the direction of personalities. It is clearly the duty of the inspector to teach the production man just what he means by "correct quality goods"—a term which needs more explaining than the mere acceptance by routine trial with gauges, hardness tester, etc. Accordingly the chief inspector should be as conversant as possible with the various manufacturing processes, which may be continually being altered by production or time-study engineers, chemists, foremen or operators, as these alterations in procedure may culminate in a noticeable difference in the quality of the final product. In other words, the inspector should be fully aware of the factors which influence the quality of the manufactured article. He will then be able to appreciate the "production" aspect of the part which is being inspected, and to recommend or discourage the application of, say, certain factors to other parts, according to his opinion of their effect on the serviceability of those parts. In this way, the chief inspector becomes a live co-operator with the production superintendent, not only to their mutual advantage but also to the far greater benefit of the organisation as a whole.

Function of Laboratories

It is frequently the case that there are aspects of the manufactured product which require the attention of specialised experience or technical training, and this difficulty should be met by co-operation between the laboratory and inspection department. These aspects will vary considerably throughout the wide range of manufactured articles—a plant engaged in the production of delicate aneroids will demand routine *laboratory* tests on the final products, a car manufacturing concern expects *laboratory* supervision of enamels, bearing metals, etc., whilst aircraft producers rely on data prepared by the *laboratory* for the inspection of all materials and processes performed throughout the works. These few examples are sufficient to show that the functions of any two laboratories are rarely strictly comparable, but in each case it is to the advantage of the chief inspector to make full use of the specialised training of the members of the laboratory staff, be the training chemical, metallurgical, physical, physico-chemical, photographic, oil technology, etc. The issuing of specifications is often essential for the simplification of inspection of raw materials and finished goods and in this respect laboratory co-operation is again useful; indeed, there must be many knotty quality inspection problems which would bear improvement by the application of the scientific mind.

Inspection and Purchasing

The control of quality of raw materials and bought-out parts will be simplified by judicious co-operation with the purchase and production control departments in the matter of selecting suppliers who are known to be most capable of supplying correct quality goods, and also in the selection of sub-contractors or part-machinists. The logical tendency of the commercially-minded buyer is toward lowest prices and considerations of delivery—often at the risk of considerable expense which will be incurred by the extra inspection and careful examination which are inevitably required on cheaply-manufactured products.

Internal Inspection

A broad subdivision of any large inspection organisation could be indicated by the diagram:—

Raw Material Inspection

Process Inspection   Dimensional Inspection

Assembly Inspection

Final Testing

Each one of the above sections constitutes a positive step in the flow of manufacture, and it is logical that each department is regarded by the chief inspector as a distinctive type of inspection. The raw materials inspection and final testing departments have a common function inasmuch as they are both involved in the application of tests which may be direct checks on previous or subsequent inspections made at other firms. Some intimacy with the methods of production and of inspection employed at the firms concerned will greatly assist in the useful direction of the type and degree of inspection made—it is well recognised how the products of certain firms will be examined with suspicion whilst other firms' products are accepted with a very low percentage check. Conversely, a knowledge of the exact tests which will be applied to any article ready for despatch will be essential for the happy frame of mind of any inspector, and these tests should be carefully determined to the satisfaction of the different inspection departments concerned, so that discrepancies due to slightly modified testing procedures are obviated.

With regard to dimensional and process inspection, these are in contrast inasmuch as the former is usually the more skilled, whilst the inspection of process work requires thoroughness owing to the constant variations due to greater influence of personal element in this type of work. The quality of process work (heat-treatment, plating, etc.) depends almost entirely on the productive organisation and the skill of the operators, so that inspection is in no small manner bound up with the method of manufacture. The process inspector can only apply a limited number of non-destructive tests to production work, and these will not usually be completely indicative of the quality of the processed work, although any glaring errors will be detected. Furthermore, a full " quality inspection " should periodically be given to all process work by submitting samples from production for laboratory report, for it is imperative that the process inspection is such that the essential properties of the processed work are confirmed, and that the correct standards of quality are applied.

Development of Quality

After the manufacture of any article has been placed on a satisfactory economic production basis, there are normally developed a number of improvements in production methods, production costs, performance or appearance of the article and so on; but it is unusual for any determined effort to be organised for the benefit of the quality of the normally-accepted goods. This aspect of development has probably suffered neglect through the reluctance to alter production methods after they have been carefully planned and standardised; too often there is a distinct resentment to tampering with manufacturing procedures which are producing " satisfactory " work. On the other hand, it is often possible to make substantial improvements in quality of workmanship or product at negligible cost and inconvenience, and yet, it is frequently the case that no definite provision is made in engineering works organisations for improving the quality of the manufactured product. Failing the nomination of a quality engineer, periodic quality conferences should be held to co-operate the deliberations of the development, production and inspection departments, in order that the question of quality of product shall not remain at a fixed level for all time. After all, it is as important for the quality of manufactured goods to be as progressive as such commercial considerations as the methods of production, the competitive performance or usefulness of goods, or the selling organisation.

THE "TAYLOR-HOBSON" ALIGNMENT TELESCOPE

TESTING and measuring the lack of alignment between any pair of bearings becomes progressively more difficult as those bearings are more widely separated. For this reason, an optical method of alignment testing is welcome because its working accuracy is less adversely affected by the distance of which the measurement is made.

The " Taylor-Hobson " Alignment Telescope is designed to enable alignment measurements to be made to a high order of accuracy where the separation of the bearings would make the accuracy of mechanical alignment methods low.

The application of this instrument is particularly of value to the aircraft industry in which large airframe assembly jigs have to be erected and inspected at frequent intervals. The jig members must be maintained in correct relationship with one another and suitable holding devices are provided on these members to take the Alignment

Telescope so that alignment and parallelism can be checked with great rapidity. Other uses include testing the straightness of long machine tool beds and aligning a series of bearings such as are found in marine or diesel engines.

The external appearance of the telescope and collimator units is that of a pair of steel cylinders, hardened and ground to size. The length of these cylinders is such as to give a good bearing surface and their diameter is held constant between the limits 2.2495 and 2.2498 inches. Special precautions are taken in manufacture to ensure that the optical axis of the instrument, on which measurements and settings are made, coincides with the mechanical axis, which may be located by the usual means.

The telescope, in conjunction with its collimator, enables measurements of lack of alignment to be made between the axes of a pair of bearings; the angle of tilt between the axes may also be measured. The telescope is used to observe the scales in the collimator unit which allow the displacement and tilt to be read directly. The telescope unit is shown in Fig. 17. The object under observation is focused, by means of the lens F, so that its image lies in the plane of the glass plate (graticule) G_1, which bears a pair of fine cross-lines. The centre of these cross-lines lies accurately on the axis of the telescope. The eyepiece P, in conjunction with the lens E, forms a microscope system which is focused on the graticule G_1 so that the magnified images of the object and the cross-lines are seen simultaneously in the eyepiece. The telescope gives an erect image magnified about $\times$ 30. The focusing knob K, which controls the position of the lens F, is moved in a clockwise direction to a stop in order to bring into focus an object at infinity; this setting is used when measuring tilt. In the measurement of displacement, the target is brought into focus by turning knob K in an anti-clockwise direction, from the infinity position, which moves the lens away from the graticule G_1.

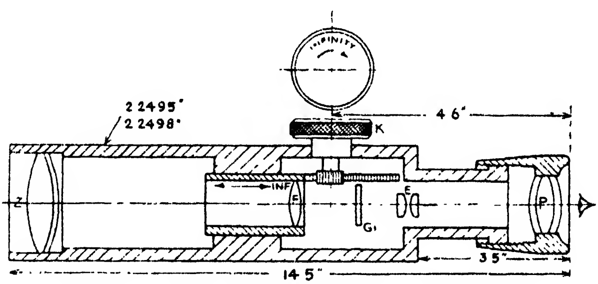


Fig. 17.—*Taylor and Hobson alignment telescopes.*

The collimator unit is shown diagramatically in Fig. 18. A low power lamp, supplied by a small transformer, illuminates the scale G_2 which is placed at the focal distance from the lens C. Light emerges from this lens as a parallel beam and is said to be collimated; looked at through lens C the graticule G_2 is virtually at infinity. In front of the lens C is another graticule G_3 bearing the scale used for measuring displacement. Between the lamp and the graticule G_3 is a lens for evening-up the illumination and also a green filter. The green background improves the contrast of the images of the scales as seen in the telescope.

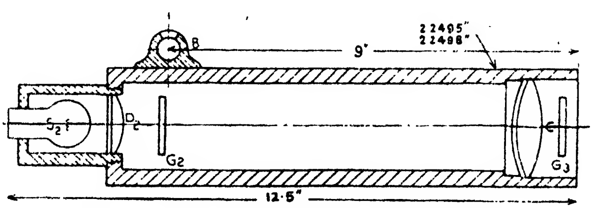


Fig. 18.—*Taylor and Hobson collimator unit.*

The scale G_2 is used for the measurement of tilt and it consists of two scales arranged at right angles, surrounded by circles, as shown in Fig. 19, each small graduation represents thirty seconds of arc.

The displacement scale G, shown in Fig. 20, carries six scales arranged around the sides of a square, together with a central star. The intervals marked are 0.010, 0.020 and 0.050 inch and the graduations are numbered from a central zero. Precautions are taken in manufacture to ensure that the scales on the graticules G_2 and G_3 are in the same orientation and that the centre of each lies accurately on the axis of the collimator.

The displacement scale G_3 is also mounted separately in a metal frame called a target plug; the central star of the graticule is accurately located on the axis of the plug. It is used when the measurements of displacement must be made where there is no room for the complete collimator; it must be illuminated independently.

The principles of measurement of tilt and displacement are shown in Figs. 21 and 22 in which the telescope is set up to view the collimator. When the axis of the telescope and collimator are inclined at an angle 'w,' the graduations of the scale G_2 will appear

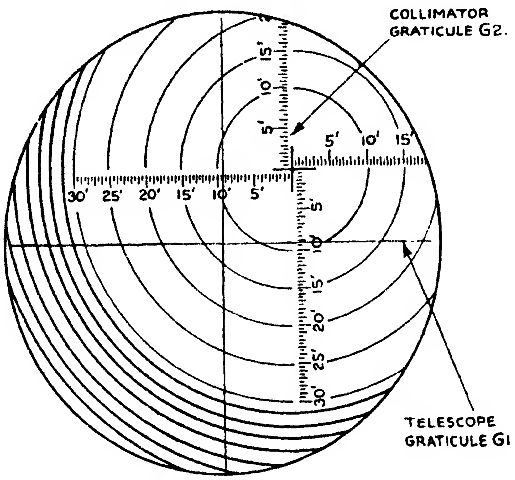


Fig. 19.—Scale for measurement of tilt.

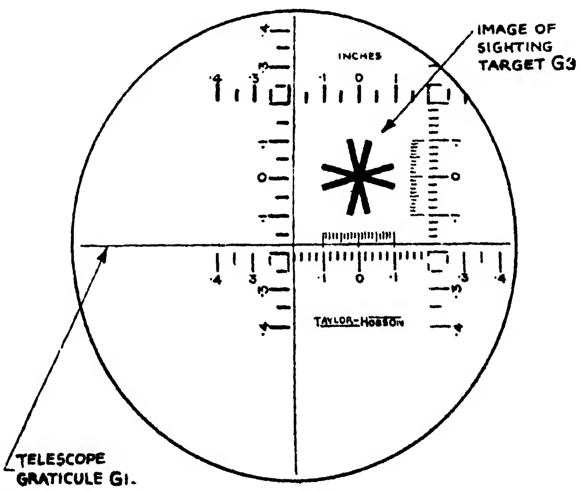
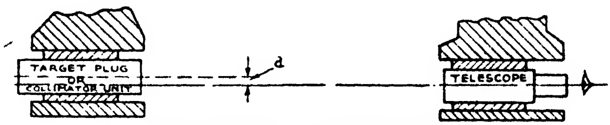


Fig. 20.—Displacement scale.

the same size, whatever the separation between the two units and the view in the telescope is as seen in Fig. 19. The small spirit-level built into the collimator enables the two scales of the tilt graticule to be set vertically and horizontally, so that, having set the telescope cross-lines parallel with the scales, the tilt may be measured in two meridians at right angles. Thus, in the figure, the tilt between the axis is 9¼ minutes in a vertical meridian and 9½ minutes in a horizontal meridian. The concentric circles on the outer part of the scale are used when the tilt is greater than 30 minutes of arc; up to a limit of 2° one or more of these concentric arcs can be seen in the telescope and so give some clue to the direction of the collimator axis. Preliminary adjustment to within 2° can easily be made by eye.



MEASUREMENT OF DISPLACEMENT d

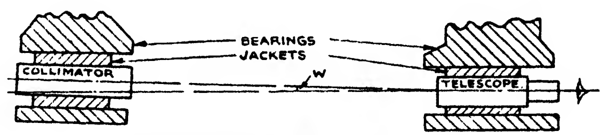
FIG. 21

A lateral displacement ' d ' between the axis is shown in Fig. 21, with the corresponding image seen in the telescope in Fig. 20. The displacement in a vertical meridian will be seen to be 0.180 inch and that horizontally 0.180 inch.

The size of the image of the displacement scale G_2, as seen in the telescope, depends on the distance separating it from the telescope; hence, the size of the graduations appears less as the distance increases and the accuracy of measurement decreases correspondingly.

The central star on the displacement scale is made up of four V's at intervals of 90°. When the axis of telescope and collimator are aligned the cross-lines of the telescope fit exactly into the star so as to bisect each V exactly. Any slight lack of alignment, even though too small to be measurable on the scales, is apparent because the cross-lines are seen to cut one side of the V instead of splitting it at its apex. This alignment test is extremely sensitive.

The range over which the instrument may be used is from 2 feet 6 inches to about 100 feet in still air. The accuracy of measurements of relative tilt between the axis of the two instruments is independent of their separation. The smallest interval on the tilt scale is 30 seconds; each of these can be further subdivided, by eye, into five parts, hence measurements may be made to plus or minus 6 seconds of arc.



MEASUREMENT OF TILT W

FIG. 22

Accuracy of displacement measurements varies with the distance over which the measurement is made, since the scale divisions appear larger at close quarters and so may be more accurately subdivided by eye. Up to 10 feet the smallest intervals 0.010 inch can be subdivided by estimation to plus or minus 0.001 inch; up to 50 feet measurements can be estimated to plus or minus 0.01 inch.

When the two units have to be set in alignment, in contrast to measuring lack of alignment, the cross-lines of the telescope can be set into the V's of the central star very much more accurately than the scales can be read. This setting can be made to the order of plus or minus 0.001 inch at 30 feet separation and to about plus or minus 0.0002 inch at 5 feet.

A wide variety of problems of alignment in engineering can be solved successfully by optical means using the Alignment Telescope. Foremost amongst these is the setting up and inspection of large jigs and fixtures used in airframe assembly.

Part II

MODERN METHODS WITH AIRCRAFT MATERIALS

STEELS IN AIRCRAFT PRODUCTION

By Dr. W. H. HATFIELD, F.R.S,

(Brown Firth Research Laboratories.)

STEEL is perhaps the most important metal which is used in the construction of aeroplanes. Without the special steels the present high-powered engines and air frames which will withstand the arduous conditions to which they are exposed would not be possible, and the present attainments in the directions of high speeds, high altitudes

Fig. 23. 0.12% *Carbon C.H. Steel O.Q.* 500° *C.* 750° *C., W.Q. Steel* 1. × 300.

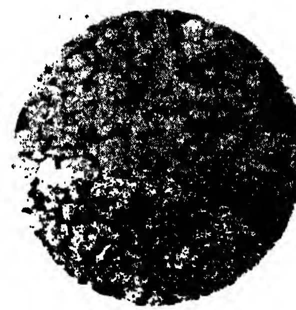


Fig. 24. 0.2% *Carbon Steel Bar, Normalised* 880° *C. Steel* 2. ×200

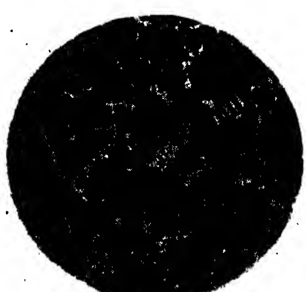


Fig. 25. 0.4% *Carbon Steel Normalised* 850° *C. Steel* 3. × 200.

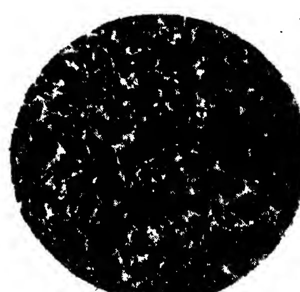


Fig. 26. 0.4% *Carbon Steel. O.H.* 850° *C. T.* 600° *C. Steel* 3. × 200.

and weight-carrying capacity could not have been attained. In other words, the development of the aeroplane has only been rendered possible by development of the special steels to meet the special properties desired. These requirements are not all concerned with the mechanical properties of the steels, and various physical properties

such as coefficient of expansion, density, thermal conductivity, magnetic properties have also frequently to be considered. For example, the special Nickel Manganese Chromium Steel D.T.D. 247 was developed in the author's laboratories in order to provide a steel with a co-efficient of expansion as near as possible to that of aluminium, and this steel is now used for sleeves for sleeve-valve engines and for valve seat inserts.

It is essential on account of the high duty to which the steels are subjected that they should be of the highest possible quality, and in consequence the supply of steel for aircraft is a specialised industry demanding extreme care and control in all the stages of manufacture. For the vital parts of the engine and air frame, special care in the steel-making processes has to be exercised in order to ensure that the steel is free from harmful non-metallic inclusions, and the casting, forging and heat-treatment conditions must be carefully controlled to ensure that the steel is free from cracks or other defects.

Control of mechanical properties is achieved by variation of the carbon content of

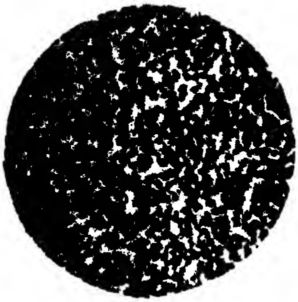


Fig. 27. 0.55% *Carbon Steel Cylinders* (*S.*70.—*S.*79.) *Normalised* 820° *C.*
Steel 4. × 200.

Fig. 28. 0.7% *Carbon Key Steel Normalised* 810 °*C.*
× 200.

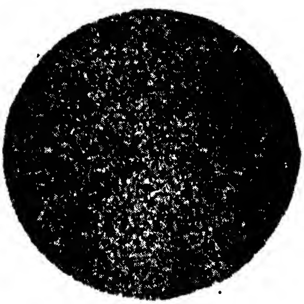


Fig. 29.—3% *Nickel-Chrome Steel. O.H.* 830° *C. T.* 600° *C.*
Steel 9. *Table III.* × 200.

Fig. 30.—*Air Hardening Nickel-Chromium Steel.*
A.C. 820° *C.* *T.* 200° *C.*
Steel 11. × 200.

the steel and by the addition of various alloying elements, the chief of which are nickel, chromium, molybdenum, vanadium, manganese, silicon, titanium, tungsten and cobalt. By suitable choice of the alloying elements and of the amounts added a variety of characteristics can be obtained to suit particular requirements and a large number of different specifications have been drawn up to deal with the various steels which have been found useful. Those commonly used in the power unit are given in Table I and those in the air frame in Table II.

Plain mild carbon steel has the advantage of being readily welded and can be easily fabricated into forms suitable for lightly stressed parts. Where alloy steel parts have to be welded the carbon content is also kept low, generally below 0.3%, since, with higher amounts, difficulties arise in welding, due to cracking, embrittlement or other troubles.

For parts such as cylinder barrels, which are subjected to heavy wear, a higher carbon steel containing 0.40 to 0.60% carbon is used. Such parts are usually put into service in the normalised condition obtained by air cooling the part from a temperature of the order of 830° to 880° C. For improved properties the steel is sometimes oil-hardened from 830° C. and tempered at 600° C.

In general, apart from the highly alloyed austenitic steels, the alloy steels are usually hardened and tempered, since it is only in this way that the high-tensile properties combined with a good degree of ductility and toughness can be obtained. The choice of alloys depends on a number of factors, the main one of which is the mass of steel treated. Nickel, together with chromium, facilitates hardening the steel and improves the hardness penetration in the interior parts of substantial section. Molybdenum tends to maintain high notched bar impact strength and is also useful in maintaining strength at moderately elevated temperatures.

Fig. 31.—5% *Nickel C.H. Steel.*
O.Q. 830° *C.* *W.Q.* 750° *C.*
Steel 8. *Table III.*

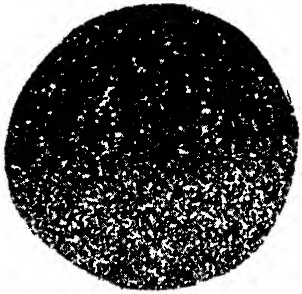


Fig. 32.—*Chromium-Aluminium Nitriding Steel.* (*Nitrided Case*)
Steel 18. × 100.

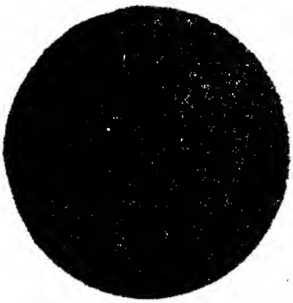


Fig. 33.—*Stainless Iron*
A.C. 1000° *C.* *T.* 700° *C.*
Steel 20. *Table V.* × 200.

Fig. 34.—*Medium Carbon Stainless Steel. O.Q.* 950°*C. T.*650°*C.*
Steel 23. × 200.

Parts required to resist wear require high surface hardness. This can be achieved by a steel of the air hardening type such as 2S28 or by surface hardening. As regards the latter, carbon case hardening and nitrogen hardening treatments are mostly used

but other methods such as flame hardening or high-frequency heating methods are sometimes employed. As regards the carbon case hardening steels, alloy additions are made where increased core strength is also desired.

For the nitrogen hardening process or "Nitriding," as it is called, several types of steel have been developed having different properties both as regards the core strength and ductility and the ultimate hardness of the nitrided case. The process has many advantages over carbon case hardening on account of the simplicity of the treatment, which consists of heating the steel in an atmosphere of ammonia at the comparatively low temperature of 500° C. Apart from the possibility of obtaining a case with increased surface hardness as compared with that possible by carburising there is much less danger of distortion of the part during the treatment of the several types of "Nitralloy" steel, the ones containing approximately 3% chromium and 0.5% molybdenum are mostly used for aircraft. These can be hardened to a case depth of 0.03 inch with a surface hardness of the order of 800 to 850 diamond hardness number. Nitrogen hardening is also applied to other alloy steels where wear resistance is required, such as, for example, D.T.D. 49B valve stems and D.T.D. 247 sleeves for sleeve-valve engines. One important advantage of nitriding is the increase in fatigue resistance to parts subjected to fluctuating bending stresses. Another method of improving wear resistance is by the deposition of hard metals, such as, for example, the "Stelliting" of seats and feet of D.T.D. 49B valves.

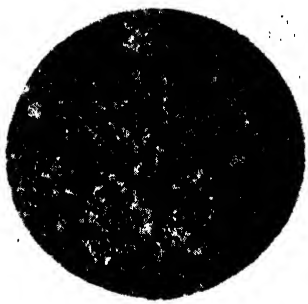


Fig. 35.—High Chromium - Low Nickel Steel. O.Q. 950° C. T. 520° C. Steel 25. × 200.

Highly alloyed steels are used where special properties are required, e.g., for corrosion resistance, scaling resistance, high mechanical properties at elevated temperatures or special physical properties.

Of the corrosion resisting steels there are three main types: (1) The plain chromium steels with approximately 12.0% of chromium (S.61 and S.62); (2) the high chromium low nickel type with 16 to 20% chromium and 1 to 3% nickel of the S80 type; and (3) the high chromium high nickel austenitic types containing essentially 18% chromium and 8% nickel (D.T.D. 166B, D.T.D. 171B, D.T.D. 176A, etc.). Steels of the last group usually also contain up to about 0.7% titanium to confer the necessary resistance to intercrystalline corrosion.

Tables III and IV give typical analyses of the various types of steels, together with the specifications to which they conform and the mechanical properties obtained on them. It is not possible in this short article to give a full exposition of the metallography of aero steels, but as it is an advantage to have some picture of the internal structure of the metals used, a few microphotographs of different types of steels will be of interest. In Figs. 23 to 28 representative structures are given for the plain carbon steels. These show the changes in structure obtained by increasing the carbon content and by hardening and tempering. In the normalised condition the carbon exists as iron carbide in the form of lamina in the dark etching constituent called pearlite. The white areas, ferrite, consisting of iron substantially free from carbon. In quenched steels the structure consists of martensite, which usually takes a needle-like formation,

Table 1

Steels commonly used in the Power Unit

Specification Number	Composition, % Carbon	Manganese	Nickel	Chromium	Molybdenum	Vanadium	Tensile strength, tons/sq. in.	Remarks
2S21	.25 max.	1.0 max.	—	—	—	—	25/35	Mild carbon steel.
7S71 and 2S77	.25/.35	1.20 max.	—	—	—	—	25/40	Mild carbon steel.
3S6 and 2S76	.35/.45	1.20 max.	1.0 max.	—	—	—	35/50	Carbon steel.
S.70 and S. 79	.50/.60	.40/.75	—	—	—	—	45/55 min.	Carbon steel.
4S11	.25/.35	.45/.70	2.75/3.75	.50/1.0	—	—	55/65	
S.65	.22/.28	.35/.65	2.75/3.50	1.0/1.40	.65 max.	.25 max.	65/70	Direct hardening steels.
2S81	.28/.35	.70 max.	3.0/3.75	.50/1.30	.50 max.	—	65/75	
S.69	.35/.45	.50/.80	3.25/3.75	.30 max.	—	—	55/65	Direct hardening steel.
D.T.D. 331	.25/.40	.70 max.	3.0/4.50	.75/1.50	.65 max.	.25 max.	80/90	High tensile steel.
2S14	.10/.18	.90 max.	—	—	—	—	32 min.	
3S15	.10/.15	.20/.60	2.75/3.50	—	—	—	45/60	Case-hardening steels.
S.67	.08/.14	.45 max.	4.60/5.20	—	—	—	40/60	
S.90	.16 max.	.60 max.	4.50/5.50	.30 max.	.50 max.	—	65 min.	High-tensile case-hardening steels.
S.82	.18 max.	.50 max.	4.0/4.50	1.00/1.60	—	—	85 min.	
2S28	.25/.32	.35/.60	3.75/4.50	1.0/1.50	—	—	100 min.	Air-hardening steel.
D.T.D.317A	.15/.35	.65 max.	—	2.50/3.50	.30/.70	—	45/55	Nitrogen hardening steel.
D.T.D.306	.15/.35	.65 max.	—	2.50/3.50	.30/.70	—	60/70	Nitrogen hardening steel.
D.T.D.49B	.35/.50	1.5 max.	10.0 min.	12.0/16.0	Tungsten =	2.0/4.0	—	Valve steel.
D.T.D.171B	.20 max.	1.0 max.	6.0/20.0	12.0 min.	—	—	35 min.	Heat-resisting steel.
D.T.D.5A	.70/.80	1.0 max.	—	—	—	—	—	Hard drawn carbon steel for valve springs.
D.T.D.4A	.40/.50	.50/.70	—	1.0/1.50	—	.15 min.	90/110	Heat-treated alloy steel for valve springs.
D.T.D.247	.70 max.	3.50./5.50	11.0/14.0	3.0 min.	.50 max.	—	40 min.	High thermal expansion steel for valve seat inserts.

Table II

Steels commonly used in the Airframe

Specification Number	Composition % Carbon	Manganese	Nickel	Chromium	Molybdenum	Vanadium	Tensile Strength, tons/sq. in.	Remarks
							NOT WELDABLE	
D.T.D.188A	.25/.40	1.30/1.80	—	—	.20/.55	—	55/65	Direct hardening steels for wing roots, sockets, tube plug-ends, eye-bolts, highly stressed bolts, etc.
4S11	.25/.35	.45/.70	2.75/3.75	.50/1.0	—	—	55/65	
D.T.D.331	.25/.40	.70 max.	3.0/4.50	.75/1.50	.65 max.	.25 max.	80/90	High-tensile steel for undercarriage oleos, etc.
D.T.D.137A	.50 max.	1.75 max.	—	—	—	—	50/65 (0.1% Proof stress)	Sheet steel for highly stressed plate fittings.
3S4	.25 max.	.60 max.	4.50/5.0	—	—	—	48 min.	
S.86	.25/.35	.70 max.	3.0/5.0	.50/1.50	—	—	47 min. (Max. stress) 40/50 (0.1% Proof stress)	
T.50	.50 max.	1.75 max.	3.75 max.	—	—	—	50 min.	Tubes for interplane and drag struts, undercarriages and other tubular structures mechanically jointed.
D.T.D.167	.25/45	.40/.80	—	.80/1.20	.15/.30	—	45 min.	
D.T.D.254	.25/.35	.45/.70	3.0/5.0	.50/1.50	—	—	75/85	
							WELDABLE	
D.T.D.126A	.30 max.	1.75 max.	—	—	—	—	40/55	Bars and forgings for use with sheets and tubes of this group.
D.T.D.124A	.25 max.	1.75 max.	—	—	—	—	40/55 (0.1% Proof stress)	Sheets for junction plates, etc.
T.35	.30 max.	1.75 max.	—	—	—	—	35 min.	Tubes for fuselage construction.
T.45	.30 max.	1.75 max.	—	—	—	—	45 min.	
D.T.D.178	.30 max.	.80 max.	—	.80/1.20	.15/.30	—	45 min.	
							NON-CORRODIBLE	
S.80	.25 max.	—	1.0 min.	16.0/20.0	—	—	55 min.	The steel most widely used for machined fittings.
D.T.D.166B	.20 max.	—	6.0/20.0	12.0 min.	—	—	52/70 (Max. stress) .. 40/50 (0.1% Proof stress)	The most important steel for high-tensile non-corrodible plate fittings.
D.T.D.102A	.15 max.	—	—	12.0 min.	—	—	35/45	Tubes for fuselage construction—the welding of both these specifications is permitted.
D.T.D.203A	.10/.20	—	—	12.0 min.	—	—	50/65	

TABLE III
Structural Steels.

Material	No.	C.	Si.	Mn.	Ni.	Cr.	Va.	Mo.	Numbers of Specifications	Treatment	0.1% P.S. tons sq. in.	Y.P. tons sq. in.	M. S. tons sq. in.	El. %	R/A %	Izod.	Brinell	Fatigue ± tons	Mod. of Elas. sq.in.
Carbon Steels ..	(1)	.12	.18	.65	.10	—	—	—	2 S.21 En 2A En 3 (See also D.T.D.41, 82A. 2 T.26. S.84. 2 S.14)	Normalised 900°C.	16.2	17.5	28.5	37	64.5	65	124	13.5	13400
										Refined W.Q. 760°C.	14.1	17.2	31.3	33	60.9	85	137	14.0	13400
	(2)	.28	.20	.75	.22	—	—	—	2 S.71 En 4 (See also 3 S.1. 3 S.3. D.T.D.398. En 5. En 6 D.T.D. 17A.)	Normalised 870°C.	18.5	19.5	35.8	31.5	57.0	32	151	14.9	13300
	(3)	.41	.14	.50	.12	—	—	—	3 S.6. En 8 (See also 2 S.76. En 12.)	Normalised 850°C.	20.8	23.9	38.9	27	53.0	28	170	16.5	13300
	(4)	.55	.23	.58	.16	—	—	—	S.70. S.79 En 9 En 10	Normalised 830°C.	23.0	27.8	46.5	21	38.0	10	202	19.0	13250
									(See also 6 W.3, 6 W.8. D.T.D. 215, 153, 187A)	Oil Harden 830°C. Temp. 600°C.	29.5	41.0	56.0	18	55.0	12	241	22.5	13150
1½% manganese steel	(5)	.29	.19	1.4	.21	—	—	—	D. T. D. 126A, En 14 (See also T.45. D.T.D. 305, 501. T.35. 2T.1. D.T.D. 137A, T.50. 138A.) En 15 D.T.D. 124A.	Normalised 850°C.	20.5	23.6	40.2	30.0	57.0	50	187	17.5	13300
										Oil Harden 850°C. Temp. 640°C	24.0	29.1	40.5	31.0	59.0	85	187	17.5	13300
3% nickel C.H. steel..	(6)	.12	.15	.50	3.10	—	—	—	3 S.15 En 33	Refined W.Q. 760°C.	26.0	35.1	49.3	20.0	49.0	70	217	20.5	13050
3½% nickel steel ..	(7)	.43	.19	.64	3.58	0.2	—	—	S.69 En 22	Oil Quenched 850° C. Temp. 570°C.	53.0	56.4	63.8	22.0	61.0	55	293	27.0	13050
5% nickel C.H. steel..	(8)	.12	.14	.30	4.9	—	—	—	S.67. En 37 (See also S.90. En 38)	Refined 840°C. W.Q. 760°C.	25.9	40.1	58.8	18.0	48.0	28	269	26.0	13000
3½% nickel-chromium steel	(9)	.31	.14	.70	3.4	.70	—	—	S.86, S.87, S.88. En 23 4 S.11. 2 S.2.	Oil Harden 820°C. Tempered 600°C.	50.0	54.5	60.1	22.0	61.0	68	277	26.5	13100
Nickel-chromium C.H. steel	(10)	.14	.21	.40	4.49	1.2	—	—	S.82. En 39	Refined, Oil Q. 760°C.	48.3	73.0	89.0	18.0	63.7	30	418	39.0	13100
Nickel-chromium A.H. steel	(11)	.28	.15	.50	4.20	1.5	—	—	2 S.28, S.86, S.87, S.88 2T2. En 30	Air Harden 820°C. Temp. 250°C.	65.2	85.0	106.0	12.5	45.0	15	495	45.0	13150

TABLE III—*continued.*
Structural Steels.

Material	Typical Analysis: No.	C.	Si.	Mn.	Ni.	Cr.	Va.	Mo.	Numbers of Specifications		Treatment	Typical Mechanical Properties: 0.1 % P.S. tons/sq. in.	Y.P.	M. S.	El. %	R/A %	Izod.	Brinell	Fatigue + tons	Mod. of Elas. sq.in.
Nickel - chromium molybdenum-vanadium steel	(12)	.23	.18	.55	3.04	1.47	.19	.53	S.65.		Oil Q. 850°C. Temp. 640°C. A C.	65.1	68.7	73.9	21.5	69.0	48	340	32.0	13200
Chrome-molybdenum steel	(13)	.32	.13	.55	—	1.05	—	.25	D.T.D. 470. (See also D.T.D. 545, 178, 408, 535, 167.	En 19	Oil Harden 820°C. Temp. 680°C.	36.5	45.5	53.8	24.5	67 0	65	255	22.0	13150
Chrome-molybdenum high-tensile steel ..	(14)	.30	.21	.59	.89	.88	—	.94	D.T.D. 228.		Oil Q. 875°C. Temp. 640°C. A.C.	53.7	58.5	64.0	19.0	57.0	50	293	27.0	13150
High chrome-molybdenum steel ..	(15)	.23	.29	.48	.21	3.11	—	.45	D.T.D. 317A. (See also D.T.D. 306)	En 29 En 40	Oil Harden 900°C. Temp. 650°C.	38 6	44 4	53 6	25 0	71 5	109	248	22	13150
Carbon-chrome ball-bearing steel ..	(16)	.99	.21	.48	.12	1.41	—	—		En 31	W.H. 810°C.	—	—	—	—	—	—	650	—	13000
Chrome-vanadium steel	(17)	.46	.17	.57	.15	1.40	.18	—	D.T.D. 4A.	En 50	Oil Q. 850°C. Temp. 490°C.	72.0	82.5	87.0	16.0	48.0	24	402	42.0	13000
Silicon-manganese steel	(18)	.52	1.95	1.05	—	.05	—	—	D.T.D. 115	En 45	Oil Harden 860°C. Temp. 480°.	66.0	78.5	90.2	14.0	32.0	11	418	43.0	12500
Chrome-aluminium steel for nitriding ..	(19)	.39	.23	.61	—	1.63	Al 1.10	.18	D.T.D. 87A.	En 41	Oil Harden 900°C. T. 650°C.	47.6	50.2	57.5	22.5	59	50	269	24.9	12800

Table IV.

Rich Alloy Steels for Special Purposes.

Steel	No.	Typical Analysis: C.	Si.	Mn.	N1.	Cr.	Va.	Mo.	Numbers of Specifications	Treatment	Typical Mechanical Properties: 0.1 % P.S. tons	Y P. /sq. in.	M. S.	El. %	R/A %	Iz-od.	Bri-nell	Fat-igue ± tons	Mod. of Elas. sq.in.
Stainless iron bar ..	(20)	.08	.10	.12	.15	13.5	—	—	D.T.D. 53, 161. En 56A S.61.	A.C.950, T.750°C. A.C.	20.0	24.0	35.9	32.0	72	80	163	14.0	13400
Stainless iron tubes ..	(21)	.10	.21	.32	.18	13.6	—	—	D.T.D.102A, 87A,	O.H.940. T.700°C., or C. Drawn and T.	24.0	31.0	40.8	29.0	71	90	196	17.5	13400
		.11	.11	.33	.21	13.7	—	—	D.T.D.203A.	O.H 950 T 550°C.	37.0	43.5	55.2	19.0	57	45	262	24.5	13400
Stainless iron sheet and strip	(22)	.18	.29	.31	.22	13.85	—	—	D.T.D.46A. S.85. D.T.D.158, 195, 39	A.H.1000°C. T.150° C.	67.8	76.5	83.4	7.0	—	—	380	43	13400
Stainless steel bar ..	(23)	.27	.35	.26	.29	13.1	—	—	S.62. En 56 D.T.D.463	O.H.940°C T.700W.Q	34.0	38.5	50.2	25	61.5	50	241	21.0	13700
High chromium low nickel steels	(24)	.11	.13	.15	1.9	17.9	—	—	D.T.D. 146A, 185A. See also 225.	Sheet Softened 670° C.	31.0	34.0	41.8	19	—	—	202	—	13500
	(25)	.12	.29	.15	2.75	17.7	—	—	S.80. En 57 D.T.D. 60B, 163A and 199.	O.H. 950. T.550 O.Q.	40.5	46	55	22	56	45	255	24.0	13700
		.12	.30	.23	2.46	18.32	—	—	D.T.D. 168. See also D.T.D. 301.	O.H. 950. T.	64.1	71.1	80.4	8.0	—	—	377	—	13500
Austenitic chromium-nickel stainless steels..	(26)	.11	.52	.29	8.1	18.2	.61	.65	D.T.D. 171B. En 58 176A. 207 189 507A.	A.C. 1050° C.	15.3	17.5	42.9	60	62	100	175	17.5	12900
		.12	.55	.30	8.05	17.9	.63	.69	166B. 211. 181A. 236.	C.R. Sheet and Strip. Tubes. Wire Ropes. Aerial Wire.	45	50.8	66	18	—	—	—	—	12500
Chromium - nickel - tungsten valve steels..	(27)	.44	1.1	.71	14.1	14.0	2.05	—	D.T.D. 49B. En 54	Valves A.C. 950° C.	—	39	54.6	39.5	47.5	38	255	20	13000
	(28)	.34	1.39	.46	10.95	21.39	3.16	—	D.T.D.49B.	Valves A.C. 950° C.	20	38	57	25.2	35	40	269	21	13000
		.42	1.42	.12	20.7	23.5	2.8	—	D.T.D. 49B.	Valves A.C. 950° C.	20	38	54	26.0	34	42	255	20.5	13000
		.41	1.75	.92	28.5	14.4	3.2	—		Valves W.Q. 1000° C.	—	36.9	48.5	38	46	49	235	—	13000

TABLE IV—continued.

Rich Alloy Steels for Special Purposes.

STEEL	No.	TYPICAL ANALYSIS C.	Si.	Mn.	Ni	Cr.	Va.	Mo.	NUMBERS OF SPECIFICATIONS	TREATMENT	TYPICAL MECHANICAL PROPERTIES 0.1 % P.S. tons	Y.P. sq.	M.S. in.	El. %	R/A %	Izod.	Brinell	Fatigue % tons	Mod. of Elas. sq.in.
Silicon - chromium valve steel	(29)	.44	3.9	.52	.15	8.1	—	—	D.T.D. 13B. En 52	O.Q. 950. T.700° C.	45	53.2	66.2	16	32	low	290	24	12500
14% tungsten high-speed steel	(30)	.61	.25	.30	0.1	3.9	14.5	0.7 (V)	S.68	Annealed.	20.8	28.3	51.6	16.6	27.5	low	241	18	14500
Nickel - manganese - chromium (high-expansion) steel ..	(31)	.59	.30	5.1	11.9	3.4	—	—	D.T.D. 247.	As forged. A.C. 1050°C.	20.5 15.2	32.5 21	56.2 42	38 50	48 60	90 110	295 185	22 19	13200 13200
12% manganese steel (castings)	(32)	1.1	0.5	11.9	—	—	—	—	D.T.D. 9B.	W.Q. 1000° C.	—	—	—	—	—	—	210	—	—

but when this is tempered the martensite changes to sorbite in which the iron carbide is in a very fine state of subdivision. The microstructures of alloy steels of the hardening type are similar in nature to those of plain carbon steels, differing only in the amount of ferrite for a given carbon content and in the degree of fineness and composition of the carbide. Fig. 29 illustrates the structure of a 3% nickel chromium steel oil hardened and tempered 600° C. and Fig. 30 that of air hardening nickel chromium steel, air hardened and tempered 200° C. Fig. 31 shows the structure of the core of a 5% nickel case-hardened steel, and Fig. 32 illustrates the nitrided case of a chromium-aluminium nitriding steel. The four types of stainless steel are illustrated in Figs. 33 to 36. Fig. 36 is typical of steels in the austenitic condition. These steels cannot be hardened by normal methods of quenching from elevated temperatures, but they can be given appreciable degrees of hardness by cold work when the grains are heavily deformed as shown in Fig. 37.

In conclusion, it might be mentioned that of the many steels that have been employed there are several of a similar type and having similar properties. The actual steel used has been largely determined by a system of trial and error on the part of the designer, different designers having decided on different steels. Such steels are, however, often replaceable with each other except perhaps in the largest sections, and it would be possible to reduce the number of specifications considerably. This aspect is now being examined.

Fig. 36.—*Austenitic Chromium-Nickel Steel. A.C.* 1150° *C. Steel* 26. × 200.

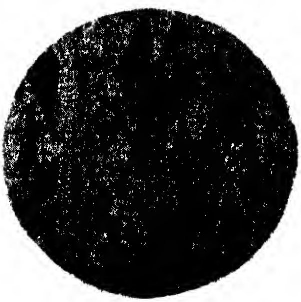


Fig. 37.—*Austenitic Chromium-Nickel Steel. Cold-Rolled. Steel* 26. × 200.

WROUGHT ALUMINIUM ALLOYS

PURE aluminium is available in several commercial grades, varying from over 98% to 99.99% purity, the chief impurities being iron and silicon. Its mechanical strength is low, however, the ultimate tensile strength ranging from 5 to about 9 tons per sq. inch, according to the amount of cold working it has undergone.

The wrought aluminium alloys, on the other hand, possess tensile strengths which often exceed 30 tons per sq. inch.

Groups of Alloys

The aluminium alloys are usually divided into two principal classes—the casting alloys and the wrought materials.

The first process in the production of all aluminium alloy articles is that of casting metal into moulds to produce the desired shape. The casting alloys are used for components on which no further working operations, other than machining, are required, while the wrought alloys are first cast in cylindrical or rectangular billets of suitable dimensions for subsequent working.

Wrought materials are produced in the desired form by the mechanical deformation of cast ingots or billets, and, as a result of this working, the homogeneity and properties

of wrought products show a considerable improvement over those of cast metal. Working may include extrusion, hot and cold rolling of sheet and strip, forging by hammer or press, and extrusion followed by drawing of tubes and wire. The wrought alloys are therefore available in the form of plate, sheet and strip; forgings; extruded sections and bars for machining or forging; tubes and wire.

The wrought aluminium alloys are sub-divided into two main groups, namely, those which obtain their mechanical strength as the result of working only and those which are both worked and heat-treated.

Work-Hardened Alloys

Cold working of any metal, such as by rolling, drawing, pressing or stamping, increases its tensile strength and at the same time reduces its ductility. The mechanical properties of work-hardened alloys thus depend on the degree of working, and many alloys can be obtained in various "tempers" up to "hard," intermediate strengths being indicated by "half-hard," "quarter-hard," etc.

Heat-Treated Alloys

The strengthening of certain aluminium alloys by heat-treatment was discovered about 1907, in an alloy similar to "Duralumin." When this alloy was quenched from about 500°C. it became soft, but after standing for several days its strength increased to a level considerably above the original figure. This was the first time age-hardening had been noticed and the changes are seen to be roughly the opposite to those occurring in the heat-treatment of steel. To-day there are other age-hardening alloys, including those which require a low temperature treatment ("tempering") to produce maximum properties.

Thus, the heat-treated alloys may further be separated into two divisions, viz., those given a single heat-treatment followed by natural ageing and those which require a double heat-treatment for the development of maximum strength. The relationship of these groups can be readily seen from Table V. It may be noted that although there are other groupings based purely on the composition of the alloys, or on their fields of application, they are not generally as convenient, from the user's point of view, as the one adopted in this synoptic Table.

Alloying Elements

The chief alloying elements in the wrought materials are :—

COPPER (Cu.), up to about 5% (for example, in "Duralumin" type alloys).

MAGNESIUM (Mg.), from about 2.5% to 7%, is the principal alloying addition in a series of work-hardened alloys, and is also present, up to about 2%, in heat-treated alloys containing copper.

MANGANESE (Mn.), up to 1.5%.

SILICON (Si.), occurs as an impurity up to about 0.5% in all aluminium alloys, and is also added in greater amounts for certain alloys.

IRON (Fe.), also occurs as an impurity in all the alloys, and up to 1.5% is added to certain types.

NICKEL (Ni.), up to about 2% increases strength at high temperatures.

Other alloying elements which may be present in certain alloys are:

ZINC (Zn.), usually in association with copper.

TITANIUM (Ti.), not exceeding 0.3%, as a grain refining agent.

CHRONIUM (Cr.), up to 0.5%.

CERIUM (Ce.) and COLUMBIUM (Cb.), not exceeding 0.3%.

The commercial alloys are generally complex mixtures, of which the following are the more important :—

Aluminium-Copper Magnesium (Cu. 4%, Mg. up to 1%), e.g., "Duralumin" type, and with increased amounts of Magnesium, Silicon or Manganese, e.g., "Super-Duralumin" types.

Aluminium-Copper-Nickel-Magnesium (Cu. 4%, Ni. 2%, Mg. 1.5%), e.g., "Y"-Alloy type; and containing one or more other elements, such as Fe., Zn., Ti., etc., e.g., "RR" Alloys.

Aluminium-Magnesium (Mg. 2.5 to 10%, Mn. up to 1% and Cr. up to 0.5%), e.g., "Birmabright" and "MG7" types.

Aluminium-Silicon (Si. either 5% or 10–13% and possibly small additions of Cu., Mg. and Ni.).

In general, the heat-treated alloys containing small additions of nickel are superior to others at temperatures above normal—for example, "Y" alloy and certain alloys of the "RR" type. They are employed for components such as pistons for internal combustion engines. A chart following page 80 shows mechanical properties.

Corrosion Resistance

Dry aluminium does not corrode, and, even in the presence of moisture, the aluminium-rich alloys are far superior to the majority of other metals.

This high corrosion resistance of aluminium-rich materials is conferred by the natural film of oxide which forms immediately aluminium is exposed to the air. The oxide layer slowly increases in thickness, until after some hours no further oxidation takes place unless the film is broken or otherwise removed. The oxide is invisible and maintains the surface bright indefinitely. It is hard but flexible and very adherent. Its thickness may be increased by anodic oxidation, thus conferring very high resistance to corrosion and abrasion.

"Clad" Sheet and Strip

Certain alloying elements which improve mechanical properties reduce corrosion resistance, and the alloys containing essentially magnesium are less liable to corrosion than those containing copper, nickel, etc.

High corrosion resistance, combined with optimum mechanical properties, is obtained by the use of a strong alloy coated with pure aluminium—for example, "Alclad," "Aldural," etc. (covered by B.S.S. 2L38, B.S.S. L47 and D.T.D. 390). Sheet of this type consists of a core of a heat-treated alloy covered on each side by a thin coating of high-purity aluminium, which prevents contact between corrosive agents and the core. It also confers electrolytic protection of the core, even at cut edges and in spots from which the "cladding" has been removed.

The pure aluminium coating is approximately 5% of the total thickness of the sheet on each side.

Contact Corrosion

As aluminium and its alloys are electro-positive to the other metals except magnesium, zinc and cadmium, electrolytic corrosion may occur when contact is made with other metals in the presence of sea-water and other reactive solutions. This action is most severe when the aluminium is touching copper-rich materials and plain carbon steels, but is relatively unimportant with stainless steel.

Dissimilar metals should therefore be insulated from the aluminium-rich alloys by the use of suitable paints, impregnated fabrics and similar materials. Steels are often cadmium or zinc-plated to reduce electrolytic corrosion when in contact with aluminium alloys.

Contact with wood in the presence of moisture may also result in corrosion, and suitable insulation is again required. As certain types of rubber and "plastics" may be harmful, a test is advisable to determine whether the use of protective paints or "dopes" is necessary.

Close and continuous contact with almost any material, including aluminium and its alloys, may cause serious corrosion unless the ingress of moisture is prevented. Suitable insulating materials are covered by D.T.D. Specification 369A.

Machineability

While pure aluminium is not regarded as being readily machineable, most of the wrought alloys present little difficulty when the recommended procedure is adopted.

Machining speeds for all the strong aluminium alloys are high, thus leading to a reduction in cost which, coupled with the saving in weight, may result in a lower total cost than if a component is made of other metals, such as cast iron. The low specific gravity of aluminium alloys also results in low inertia effects, due to the stock, in automatic machines.

Specific machining jobs require individual attention, but, in general, speeds can safely exceed those used for leaded brasses or free-cutting steels. Tool life is approximately equal to that of tools for these materials, and may exceed it. A good surface finish is readily obtained on the wrought alloys, as long as depth of cut and feeding speed are adjusted suitably. For turning, drilling, tapping and screw cutting, it is essential to give the surface of the tools as smooth a finish as possible, and lubrication is required for most machining operations.

Cold Forming

The wrought alloys, particularly those of the B.S.S. L46 type, generally possess good cold-working properties, but severe cold forming may necessitate a series of operations with intermediate annealing. The heat-treated alloys require greater care, particularly in pressing and deep drawing, and such working is carried out either on fully softened (annealed) metal or on solution-treated material within a short time of quenching or on removal from refrigerated storage chambers.

The forming of sections from strip has been extensively developed in connection with the aircraft industry, and the production of complex sections is possible. Tubes are produced in a variety of sections and sizes, and both tubes and extruded sections may be manipulated to the desired form.

The use of the drop-hammer and the rubber-pad press has extended very considerably, and large numbers of components are now produced by these processes. Soft metal, wood and laminated plastics are used for tools in the rubber press.

Jointing

Riveting has long been used as the standard method of joining aluminium sections and automatic riveting machines maintain a high rate of production on straightforward jobs. The rivets used are either pure aluminium (L36), heat-treated " Duralumin "-type material (2L37 or D.T.D. 327) or of alloys containing magnesium as the principal addition element (D.T.D. 303 and 404). They may be solid or tubular, and for liquid-tight joints, sealing compounds are employed.

Soldering and Brazing

While soldering is possible by the use of special fluxes and solders, combined with a suitable technique, it is not recommended, owing to the very low corrosion resistance of the joint.

" Brazing," however, is being increasingly used, particularly the furnace brazing process for mass-produced assemblies. As the usual brazing metal is an alloy containing silicon and melts at about 520°C., the application of brazing is limited to alloys which do not show any signs of fusion at this temperature.

Fusion Welding

Aluminium itself is readily gas-welded, provided the technique used takes into account the special properties of the metal, and detailed information on welding procedure is available. The non-heat-treated alloys are weldable, but modifications in technique are necessary; for example, increased magnesium contents necessitate different flux mixtures to remove the oxide, and a high rate of welding is essential.

The heat-treated aluminium-rich alloys can be fusion-welded, but optimum properties are not obtainable on welded components, even if it is practicable to reheat-treat the completed assembly. There is also the risk of cracking in and alongside the joint during welding.

The metallic arc process is used to a small extent only for pure aluminium and the non-heat-treated alloys, but developments in this field are expected. The carbon arc has been used to a limited extent, as also have other methods, such as the " Weibel " process.

Resistance Welding

Spot welding is applied very successfully to the high-strength alloys, but owing to their high electrical conductivity, all the wrought aluminium alloys require current densities considerably higher than those used for steels. The degree of control of current pressure and time is of extreme importance, and automatically controlled machines are available for spot welding sheets up to approximately 0.13 inch thick. Sheet can also be welded to extruded sections or several sheets can be welded together.

Seam welding has been used to a limited extent, but flash and butt welding methods are not yet employed commercially.

Surface Finishing

There are many commercial methods of finishing the aluminium alloys—polishing and similar mechanical processes, chemical etching (frosting, etc.), electro-plating, anodising, and painting, enamelling, lacquering, etc.

Anodic oxidation is the most important surface treating process for the aluminium alloys, and is used either " as formed " or after " sealing," with or without colouring, or as a base for paints. Anodising is an electrolytic process—rather simpler than

ordinary electro-plating—by which the natural film of aluminium oxide is considerably thickened to give a hard but flexible coating of very high corrosion resistance.

There are two main processes—using either chromic acid (Bengough-Stuart process) or sulphuric acid, as a basis—and there are many patents covering baths, details of operation, finishing, etc. Oxide films up to 0.001 inch thick can be obtained by the selection and control of suitable processing factors.

The film possesses the unique property of reacting with and absorbing certain dyes and pigments to give a wide range of coloured finishes. Some of these colours are not sufficiently fast for outdoor applications, however, but the undyed film, which may be varied from dull grey to silver, is extensively used outside.

It is possible to slightly thicken the oxide film by non-electrolytic processes (e.g., "Pyluminising") and such treatment is a rapid and inexpensive means of making the surface suitable for painting, enamelling or lacquering.

Paint can be applied direct to dry, clean aluminium alloy surfaces, although it is better over an anodic coating or a chemically produced film. Some of the usual paint pigments are not suitable, owing to the possibility of reaction between heavy metal oxides and the aluminium, but zinc oxide and zinc chromate are both satisfactory, the latter having a valuable corrosion inhibiting effect.

Recommendations for Specific Applications

These recommendations should be taken only as a general guide, and should be considered in conjunction with mechanical properties and other specification requirements. Details of the degree of working which can be performed on any specific alloy or information as to the best technique for welding, anodic oxidation, etc., should be obtained from the Wrought Light Alloys Development Association or from the manufacturers.

WROUGHT ALUMINIUM ALLOYS FOR CONDITIONS INVOLVING SEVERE CORROSION

Sheet and Strip :
B.S.S. L46, 2L38, L47.
D.T.D. 390.

Bars and Extrusions :
B.S.S. L44.
D.T.D. 297.

Tubes :
D.T.D. 186A, 190, 310B.

Forgings :
D.T.D. 297, 423A.

Wire and Rivets :
D.T.D. 303, 404.

WROUGHT ALUMINIUM ALLOYS FOR CONDITIONS REQUIRING MAXIMUM STRENGTH AT HIGH TEMPERATURES

Sheet and Strip :
B.S.S. 414.

Bars and Extrusions :
B.S.S. 478, 2L40, L45.
D.T.D. 130A, 410.

Forgings :
B.S.S. 533, 4L25, 2L40, 2L42, L45.
D.T.D. 130A, 246A, 324, 410.

Tubes :
D.T.D. 220A.

WROUGHT ALUMINIUM ALLOYS FOR SEVERE COLD FORMING OPERATIONS

Sheet and Strip :
B.S.S. L46.
D.T.D. 346.

Bars and Extrusions :
B.S.S. L44.
D.T.D. 443.

Tubes :
D.T.D. 310B, 440, 450.

Wire and Rivets :
D.T.D. 303, 327.

WROUGHT ALUMINIUM ALLOYS GIVING MAXIMUM MACHINEABILITY

Bars and Extrusions :

B.S.S. 6L1, 2L39, 2L40, L45.

D.T.D. 130A, 423A.

Forgings :

B.S.S. 6L1, 2L39.

D.T.D. 130A, 410.

WROUGHT ALUMINIUM ALLOYS FOR GAS WELDING

Sheet and Strip :

B.S.S. L46.

Extrusions :

B.S.S. L44.

Tubes :

D.T.D. 310B.

WROUGHT ALUMINIUM ALLOYS FOR SPOT AND SEAM WELDING

Sheet and Strip :

B S.S. 5L3, 2L38, L46, L47.

D.T.D. 182A, 356, 390.

WROUGHT ALUMINIUM ALLOYS ESPECIALLY SUITABLE FOR UNIFORM ANODIC FILMS

Sheet and Strip .

B.S.S. L46.

D.T.D. 182A, 346.

Bars and Extrusions :

B.S S. L44.

D.T.D. 297, 423, 443.

Tubes .

D.T.D. 186A, 190, 310B, 440, 450.

MACHINING OF ALUMINIUM ALLOYS

THE considerations involved in the successful machining of aluminium and its alloys have sprung into particular prominence during the war with the greatly increased use of these materials in war production, and especially in aircraft production. Numerous firms who have hitherto confined their attentions to steels and non-ferrous metals like brass and copper are now engaged in the mass production of parts machined from extruded, rolled and cast aluminium and aluminium alloys. These light metals are by no means difficult to machine, but their particular properties require a special technique if full advantage is to be taken of the economy resulting from the high speed at which they may be worked.

The large variety of alloys now in use makes it impossible to generalise as some of them demand greater attention to detail than others. It is, in fact, no more possible to recommend tools, speeds and technique which are suitable for the pure metal as well as for the different alloys, than it is to give one standardised practice for all the copper alloys or steels. On the other hand, it would be cumbersome and unnecessary to analyse each of the many alloys individually and for the sake of brevity they may be divided into groups, each of which possesses more or less distinct machining characteristics.

Many machinists have evolved their own technique after prolonged experimenting in trial and error methods, and whilst it is often desirable to do this to discover the best practice for individual components, the object of this article is to describe the fundamental rules governing light alloy machining in order to eliminate as much as possible of the tedious preliminary work.

Characteristics of Aluminium and Aluminium Alloys

Aluminium and its alloys possess in greater or lesser degree a number of physical and mechanical properties which profoundly affect their amenability to machining. The chief of these are the comparatively low resistance to penetration as typified by Brinell and diamond hardness values, the elastic modulus of only 10,000,000 lbs. per sq. inch, comparatively high coefficient of friction on steel, high thermal conductivity and coefficient of expansion, and relatively low notch impact strength. Considerable variation of these properties is to be found in the different alloys, involving corresponding

variations in the technique of machining, but in general they may be said to be characteristic of this class of material.

A study of these properties suggests that tools used for the cutting of hardwoods are more suitable than those designed for the heavy metals, and this is to a large extent true, although, of course, modifications are necessary. In many cases the use of tool angles which are most suitable from the viewpoint of cleanness of cut is not possible from considerations of tool life. Generally speaking, it may be said that tool pressure is reduced and finish improved as the tool angle decreases and the minimum angle should be used compatible with tool wear and rigidity.

It is possible to deduce a rough relationship between the Brinell or diamond hardness of the alloy being machined and the desired cutting angle of the tool, and the Table below will show that the smallest angles are required for the softest alloys and the pure metal and the largest angles for hard alloys.

Turning tool angles.

Brinell Hardness	Angle at cutting edge (see Fig. 1)			
	Top rake (a)	Cutting angle (b)	Clearance angle (c)	Side rake (d)
Up to 50	45° to 54°	30° to 35°	6° to 10°	10° to 20°
50 to 80	35° to 49°	35° to 45°	6° to 10°	10° to 20°
Over 80	30° to 39°	45° to 50°	6° to 10°	10° to 20°

This Table can be taken only as a general basis since such factors as the chemical composition and mechanical condition of the alloy, that is, whether it is heat-treated, strain hardened or in a soft state, also exert considerable influence upon both surface finish and tool wear. For example, alloys containing high percentages of silicon, such as N.A.161 covered by Specifications D.T.D.240 and D.T.D.245, require to be machined much more slowly than their hardness would suggest and in order to obtain fine surface finish it is necessary to use tools tipped with cemented carbide. Indeed, when machining automobile pistons cast in these alloys it is usual to follow this with a fine cut with a diamond tool, since the presence of occasional particles of free silicon will in time dull the cutting edge even of tungsten carbide. Alloying elements which do not form very hard or abrasive constituents tend to assist machineability. Examples of these are copper, zinc and magnesium, all of which form solid solutions with aluminium. Other elements such as silicon, mentioned above, and manganese, which form very hard or tough constituents, are liable to increase tool wear and reduce the quality of finish.

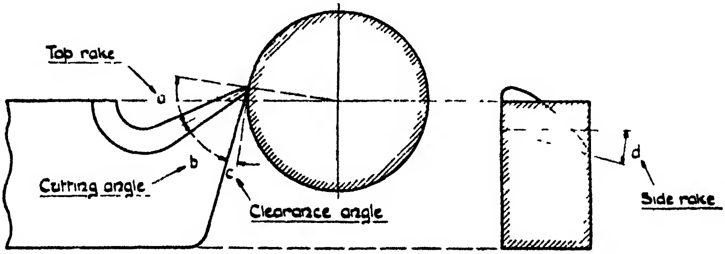


Fig. 38.—Typical Tool for Turning aluminium alloys.

High temperature (solution) heat-treatment applied to an alloy has a tendency to improve machineability at some expense of tool life and to produce long turnings, as its effect is to dissolve the constituents in solid solution. Artificial ageing or precipitation treatment may greatly improve machining properties, but as it also hardens the alloy, tool wear usually becomes a little higher. Castings incline to be more free cutting than wrought alloys since the structure is less homogeneous and the constituents situated at the grain boundaries assist in chip breakage. These constituents are largely broken down by the working which wrought materials receive during manufacture, and when

these are required to have free cutting properties it is necessary to introduce into their composition special elements which cause chip breakage, as well as to give special treatment for the same purpose. Such elements are usually metals which are either insoluble or of very limited solubility in aluminium, and very successful results have been obtained by these methods. Wrought aluminium alloys have now been produced possessing high strength and free cutting properties almost equal to the leaded brasses, and the small chips produced when machining these alloys render them most suitable for the manufacture of components on automatic and screwing machines.

Grouping of Alloys with regard to Machining Properties

In this grouping the cast alloys are separated from the wrought since the structure of the former generally tends to confer free cutting properties; nevertheless, there is a number of cast alloys, chief of which is N.A.226, which it would be feasible to include with the strongest wrought alloy group as their machining properties are very similar.

It should not be assumed that the machining properties of all alloys in any group are identical, but a technique which gives good results with one alloy should be satisfactory for others in the same group without drastic modification.

Group I.—**Not Heat-treated Wrought Alloys**

N.A.2S. to Specifications B.S.S.L.4, L.16, L.17, L.34, L.36 and 4T.9.
N.A.3S. to Specification D.T.D.213.
N.A.4S. to Specifications B.S.S.L.44, L.46, D.T.D.249, D.T.D.266 and D.T.D.310B.
N.A.57S. to Specifications B.S.S.L.44, L.46, D.T.D.296 and D.T.D.310B.

Alloys in this group offer little resistance to cutting, that is, tool pressure is low, but care is required to obtain good surface finish as they are all inclined to be "luggy," N.A.2S. and N.A.3S. being worst in this respect. Since their hardness is comparatively low, large top rake angles are necessary, as well as a suitable lubricant. Turnings are long and straight except in the case of N.A.4S., with which there is a tendency for them to curl a little.

Group 2—**Heat-treated Wrought Alloys**

N.A.17S. to Specifications B.S.S.6.L.1, 5.L.3, 2.L.37, 2.L.39, 4.T.4, D.T.D.147 and D.T.D. 150.
N.A.19S. to Specification B.S.S.4.L.25.
N.A.21S. to Specifications B.S.S.2.L.40 and B.S.S.L.45.
N.A.26S. to Specification D.T.D.364A.
N.A.62S. to Specifications D.T.D.423A, D.T.D.443, D.T.D.450 and D.T.D.460.

This group includes alloys which vary considerably in hardness, and differing cutting angles and top rakes are therefore required according to this variation, as recommended in Table I. All the alloys except that to N.A.62S. have fairly high percentages of copper in their composition, which copper is in solid solution after heat treatment. They can be machined to a good finish with or without a lubricant, the turnings usually coming off as long curls. The silicon content of D.T.D.423 alloy may cause a tendency for the building up of burrs on the cutting edge rather more than with the other alloys, but this can be minimised by suitable lubrication. D.T.D.443 and D.T.D.450 alloys are softer than D.T.D.423A, although of the same chemical composition, and for this reason tend towards slight "lugginess."

Group 3—**Casting Alloys**

N.A.237 to Specification D.T.D.428.
N.A.250.
N.A.350 to Specification D.T.D.300.
N.A.218 to Specifications B.S.S.2.L.24 and L.35.
N.A.226 to Specifications D.T.D.298, D.T.D.304 and D.T.D.361.
N.A.244.

A fairly wide variation in cutting properties exists in this group. N.A.250 and N.A.350 may be termed free machining alloys as the chip size is small, and they may be machined to a very good finish using high cutting speeds with small feeds and cuts. These two alloys possess the best cutting properties of all the casting alloys. The remaining alloys in the group machine well, the surface finish being good and the turnings tightly curled and long. The turnings may become a problem, in which case the cutting speed should be reduced. The last three alloys have very similar cutting characteristics to those of the wrought alloys in Group 2.

Group 4.—Cast and Wrought Alloys requiring special considerations.

Cast Alloys

N.A.116.
N.A.117 to Specification D.T.D.424.
N.A.123.
N.A.125 to Specifications D.T.D.272 and D.T.D.276.
N.A.160 to Specifications B.S.S.L.33 and D.T.D.231.
N.A.161 to Specifications D.T.D. 240 and D.T.D.245.
N.A.162 (Lo-Ex).

Wrought Alloys

N.A.33S.
N.A.35S.
N.A.38S. to Specification D.T.D.324.

These alloys contain medium to high percentages of silicon, as well as other elements in some instances. Those containing up to 5% of silicon, such as N.A.116, N.A.123, N.A.125 and N.A.33S., are inclined to be rather "luggy" and present a somewhat grey surface after machining. The chips tend to be torn rather than sheared from the work, demanding the use of tools with large top and side rake angles and comparatively low cutting speeds. As with all members of this group a cutting lubricant and coolant assists greatly in the attainment of good finish, tests having shown that there is a rapid deterioration as the temperature of the work increases.

Alloys of the types N.A.160, N.A.161, N.A.162, N.A.35S. and N.A.38S. contain between 11% and 14% of silicon and are generally considered to be the most difficult aluminium alloys to machine. In addition to their being "luggy" by nature, the high silicon content together with the occasional presence of hard free silicon particles causes rapid tool wear, making it impossible to use the large rake angles which should be employed for material of their hardness. High-speed steel tools are not advisable except for short runs, but the use of tools tipped with cemented carbides gives excellent results. For finish of the order demanded of pistons and similar parts it is usual to take a final cut of a few thousandths of an inch with a diamond tool. It should not be inferred from this that high-speed steel tools are entirely unsatisfactory with these materials, they are in fact often used but rather more than normal tool wear must be expected.

Cutting Materials

Tool wear depends upon a number of factors, chief of which are cutting speed, shape of tool, alloy, efficiency of cooling and lubrication, and material from which the tool is constructed. A series of tests has shown that with cutting angles larger than those recommended, i. e., over 54°, crushing of the chip occurs instead of clean shearing when depths of cut are taken in excess of .118 inch. Aluminium and aluminium alloys tend to work harden rapidly under these conditions and increased tool wear results. It should be noted, too, that as these chips or curls are so much harder than the original stock they will scratch it heavily unless care is taken to lead them clear of the work.

These facts account for the recommendations to use cutting angles not in excess of 54° and where working conditions render this impossible, it is best to use tools tipped with tungsten carbide, as the great hardness of this material enables the increased wear to be withstood. It is, indeed, usually necessary with carbide tools to have cutting angles of not less than 65° owing to their brittleness. Tungsten carbide tools are of course relatively expensive, and are mainly used for machining hard or abrasive alloys on such machines as capstan or automatic lathes, where a tool life of at least eight hours is required.

For use on all but the most abrasive aluminium alloys high-speed steel is very satisfactory as it is tough, abrasion resistant, and retains its edge up to a dull red heat. It should be used in preference to carbon steel except for drills, reamers, dies, taps and tools operating at low temperatures, in which case the latter material is quite satisfactory owing to its ability to hold a keen edge. A keen edge is essential for the attainment of good surface finish and the top surfaces of tools over which chips have to pass and the flutes of drills, reamers and milling cutters should be polished, as this aids chip clearance by reducing friction. Also, tools should be touched up with an oil stone after grinding and between roughing and finishing cuts as this reduces the tendency for pick-up on the tool edge.

With the harder alloys in particular a lubricant greatly assists in keeping friction between tool and work at a low level and this again reduces tool wear.

The Functions of Cutting Fluid

The main function of a cutting fluid is to preserve as long as possible the edge of the cutting tool, and hence prolong its life, and at the same time to maintain the surface finish of the work at a high standard.

The latter is a natural result of keeping the tool edge in sharp condition and is further helped by the action of the lubricant in reducing the tendency for metal to build up on the tool.

The action of increasing tool life and finish of work is achieved by the lubricating effect of the cutting fluid between tool point and work, and tool face and chip; and also by the dissipation of heat due to friction between tool and work and internal friction in the metal resulting from the shearing of the chip.

Additional and more secondary functions of cutting fluids are the removal of swarf, this being of particular importance in drilling, milling and sawing, and the laying of dust in grinding operations.

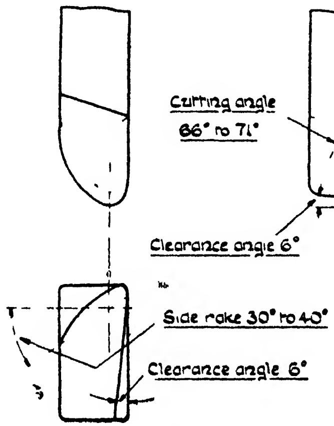


Fig. 39.—Roughing Tool for planing aluminium alloys.

Types of Cutting Fluids

There are several types of fluids in common use, chief among which are soapsuds, soluble oil emulsions in water, paraffin oil, mixtures of paraffin with lard oil or mineral oil, pure lard oil, and mineral oils compounded with sulphur. The soluble oil emulsions combine excellently the functions of cooling and lubricating and are very suitable for drilling, sawing, milling, turning, and in fact for all but the heaviest operations such as tapping and screw cutting. Owing to the low amount of oil present, usually less than 5%, their lubricating properties are not as good as lard or mineral oils with or without paraffin, and these latter should be employed for heavy cuts and slow feeds and in roughing work and tapping. A fluid which, it is claimed, gives a specially good finish, consists of a mixture of soft soap and alcohol with 38% of water.

Although many alloys can be machined dry to a good finish, for production work one of the above cutting fluids is strongly recommended. It should be added that in view of the high coefficient of expansion of aluminium, the workpiece should be thoroughly cooled before calipering for the final cut, otherwise there is a danger that it will finish undersize.

Cutting Tools

In the following pages the various processes of machining are reviewed separately and from these it will be seen that an axiom for the successful machining of aluminium might be, " Use always the smallest cutting angle compatible with the hardness and abrading properties of the alloy being machined." If this is combined where possible with a reasonable degree of side rake then little trouble should be experienced.

Lathe Tools

High-speed steel or, for abrasive alloys, cemented carbide tools should be used unless a few components only are required, when carbon steel might be substituted. A round-nosed tool is suitable for both roughing and finishing, and either a separate tool should be kept for the latter or else it should be re-stoned between the two operations. Fig. 38 illustrates a good general-purpose tool for machining aluminium alloys. In American practice the tool is often set with the cutting edge making contact on a diameter at 45° to the horizontal, all the tool angles being relative to this position. As the thrust component is then along the axis of the tool, chatter due to play in the cross slide is eliminated, but the drawback to this practice is that if much metal is to be removed, frequent resetting is necessary.

In the case of wide profile tools often used on capstan and automatic lathes, large top rake angles are seldom possible owing to the chatter they tend to produce and are also undesirable as the profile is altered when the tool is redressed. Tools with no top rake may be used but speed should be reduced considerably and tungsten carbide is advisable if maximum tool life is to be obtained.

Shaping and Planing Tools

Although similar to lathe tools in principle, shaping and planing tools require much more side rake than the former. The roughing tool should do the majority of the cutting on its side and should be of the round-nosed type. The finishing tool does not need to be so robust and the top and side rakes can be increased to the maxima shown in Fig. 40. The cutting here is done mainly by the bottom of the tool, which should have a flat base. With such large rake angles these tools are somewhat fragile and care should be taken to see that they do not suffer by striking the work on the return stroke.

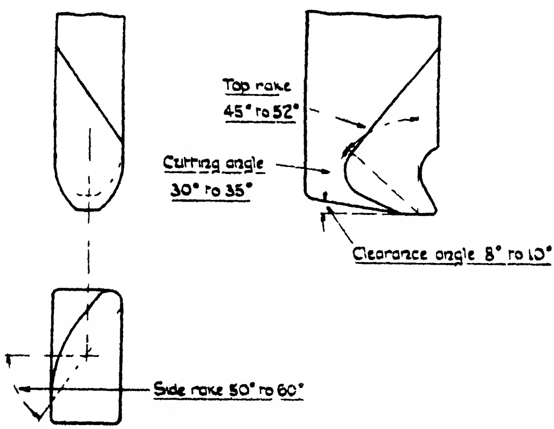


Fig. 40.—Finishing Tool.

Milling Cutters

Where it is possible to use them, the most suitable types of milling cutters are those of the inserted tooth kind, since a large diameter and consequently high cutting speed can be obtained and it is also easier to employ the correct cutting angles. The best angles, though these should be varied to suit the hardness of the material, are the same as those given in Figs. 39 and 40 for shaping and planing tools. Tests have shown that for a given volume of metal removed, the power required increases with the number of cutters. However, since the correct number of teeth depends upon factors such as the cutting speed and disposition, this should be determined by experiment.

Ordinary cylindrical milling cutters should have helical teeth, inclined at from 20° to 40° to the axis. This gives side rake which assists in the clearance of chips. To eliminate the axial thrust resulting from this helix angle a combination of two interlocked cutters with their helics running in opposite directions is frequently used.

Tapping and Threading

In designing screw parts in aluminium or aluminium alloys very fine threads should be avoided owing to the tendency to seize, and where screws have to be occasionally turned they should always be well lubricated or treated with an anti-seize compound.

Taps used for steel or brass are definitely not suitable since they do not have top rake on the cutting edge. The correct type of tap for aluminium is illustrated in Fig. 41 and should have the face undercut to give a cutting angle of 40° to 45°.

The back of the lands should be radial or slightly undercut in order to prevent clogging when backing out. Spiral fluted taps are quite successful and they certainly provide a degree of side rake. Taps which have a taper ground on the front end as shown in Fig. 41 cut quite cleanly, as they tend to push the chips in front of them, but for this reason they are not suitable as bottom taps.

The same considerations hold for dies as for taps, that is, a top rake should be ground on the cutting face and the back face should be radial to allow cutting to take place when backing out.

For lathe screw cutting the tool should have a large top rake, and may either have no side rake, in which case it should be fed in at right angles to the work, or side rake may be provided and the tool fed in at half the screw angle, cutting only on its leading edge.

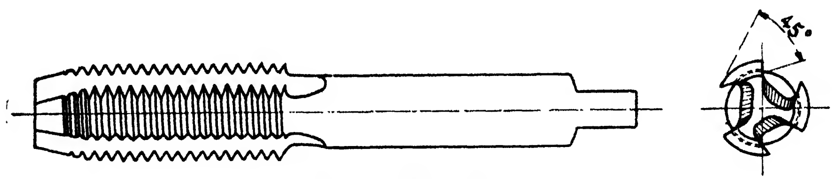


Fig. 41.—*Three-fluted tap.*

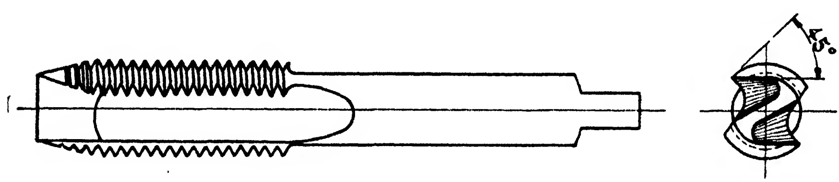


Fig. 42.—*Two-fluted " Gun " tap.*

Drills and Reamers

The drilling of aluminium does not always receive the consideration that it should, probably owing to the fact that reasonably good results are obtained with normal equipment.

To obtain optimum results, however, very high rotational speeds are required and to meet this demand machines have now been produced which operate as high as 20,000 r.p.m. The point angle should be rather larger than is used for steel, say 130° to 140°, and the rate of feed should be two or three times as fast as for steel.

For the same power consumption, three or four times the volume of aluminium may be removed than is possible with steel.

The normal twist drill with a 28° angle of helix gives quite good results for shallow holes, but with deep holes a smoother finish is obtained by the use of twist drills with a helix angle of 40°. This large twist angle gives a more acute cutting angle, but the resistance to chip clearance is greater and a coolant and lubricant should always be used.

The most suitable reamers for use with aluminium and aluminium alloys are of the spiral fluted type, the straight fluted kinds tending to produce chatter. Contrary to usual practice carbon tool steel is very satisfactory as a material for their manufacture.

Saws

The principles of sawing are similar to those of milling as it is essentially a " chisel" operation. Saws with alternately staggered teeth are frequently used and a top rake of 15°–25° is desirable, although with a large top rake a positive feeding device is necessary, otherwise there is a danger of the teeth feeding themselves into the work. All fillets between teeth should be smooth and radiused to prevent clogging of chips.

High-speed band saws and circular saws are being successfully used for cutting sheet and small sections, but heavy work such as large extruded bars, forgings and castings are usually cut with slow-speed heavy circular saws. All sawing operations are much improved by the use of a copious supply of cutting fluid and in general coarse teeth will give the best results.

The most suitable blades for hand hacksaw work are those of the "wavy-set" kind, having relatively few teeth per inch, and occasional lubrication with paraffin will reduce the effort involved.

Files

Chisel cut files, particularly those with fine teeth, are unsuitable for aluminium, since they quickly clog and mar the work.

Special files with large, smooth, milled teeth are necessary, and a wire brush should be used frequently to remove any chips which may collect. Alternately, when a considerable amount of filing work is involved a bath of hot 20% caustic soda may be provided into which the files are plunged for a few minutes prior to washing in hot water. Apart from the finish, which is much improved, these milled files remove a larger volume of metal than do the normal kind. In general, bastard cut files will produce a better finish than those with finer cuts.

Cutting Speeds

One of the most important features of aluminium and aluminium alloys, and one which has a decided influence in reducing costs of manufactured parts, is the very high speed at which they may be machined. In many cases the machines themselves are the limiting factor in this respect, preventing maximum economy being effected, but many tool manufacturers are aware of this and it is probable that costs will be lowered even more when machines especially designed for light metals are in common use.

The following table (from Zeerleder) indicates the ranges of speed at which various cutting operations may be carried out, the slower speeds, in each case, being for the harder and more difficult alloys.

TABLE VI.

Operation	Metres per minute	Feet per minute
Milling		
Roughing	400–1,200	1,300 to 4,000
Finishing	600–1,700	2,000 to 5,600
Turning		
Roughing	200–250	650 to 800
Finishing	600–1,200	2,000 to 4,000
Sawing	2,000–4,000	6,500 to 13,000
Drilling		
Without jig	200–400	650 to 1,300
With jig	100–200	330 to 650
Reaming	20–60	65 to 200
Boring		
With flat boring drill ..	30–50	100 to 160
With boring bar ..	20–25	65 to 80
Tapping and screwing ..	10–40	30 to 130

COLD FORMING OF HIGH-STRENGTH SHEET

Cold Forming

THE alloys available for cold-forming comprise a wide range, those generally classed as the high-strength materials being of the heat-treatable type. A development which must at the present time be regarded as of especial importance with regard to aircraft materials is the evolution, by light-alloy manufacturers, of sheet alloys which may be safely subjected to simple forming operations in the fully heat-treated condition.

From the quantitative point of view, however, greater importance attaches to those materials which are normally formed in the solution-treated condition. Alloys falling into this category are of two types. First, the natural ageing type, in which maximum mechanical properties are achieved by age-hardening at room temperatures for a

period lasting up to five days, and, secondly, the artificial-ageing double-heat-treatment type, which needs a further low-temperature treatment—at approximately 170°C.—after the solution treatment, in order to realise maximum mechanical properties.

An example of the former type is Alclad to D.T.D. 390. The use of this alloy, the core of which contains approximately 4.3% of copper, 1.0% magnesium, and 0.6% manganese, the coating being of 99.7% purity aluminium, has not only enabled aircraft production to be speeded up, but has also resulted in considerable economy of equipment, time and labour. The alloy, in the heat-treated condition, reaches a proof stress (0.1%) of 15 tons per sq. inch and an ultimate tensile strength of 25 tons per sq. inch, the elongation on 2 inches being 15%.

Available Working Period

Alloys of the second type remain stable for an indefinite period after solution treatment. Consequently, the time available for cold-forming operations does not present any awkward problems, and the materials can be supplied to aircraft manufacturers in the solution-treated condition. Here, again, the ability to avoid solution treatment in the fabricating plant constitutes a definite advantage.

Except in the case of simple forming operations, the natural-ageing alloys, however, can be cold formed only for a period lasting between one and two hours after solution treatment. The two-hour limit, it must be pointed out, is available only for fairly easy pressings, any severe forming should be carried out as nearly as possible within the hour. Considerable importance, however, attaches at the present time to the recent development of methods of storing high-strength sheet in refrigerated chambers. This delays the age-hardening process, with the result that forming may be carried out after a considerable interval (a time of up to 100 hours has been cited) subsequent to solution treatment.

In view of the limited period available for forming natural-ageing alloy sheet, the development of refrigeration storage in this direction will undoubtedly be watched with great interest in the future. The method has long been used for the storage of duralumin-type rivets, but the potentialities with regard to sheet have been but recently investigated.

Probably the most important precaution to be observed with regard to the cold forming of sheet is that the solution-treatment operation should be carried out strictly in accordance with requirements laid down for each specific alloy. Salt baths, using either sodium nitrate or a eutectic mixture of sodium and potassium nitrates, are more generally preferred for the solution treatment of sheet. They possess the important advantages of being able to raise the sheet quickly to the treatment temperature and of being extremely convenient in operation. Temperature must be kept within the stipulated solution-treatment range. In particular must overheating, a common cause of cracking, be avoided.

Whilst very appreciable amounts of cold forming can be carried out on sheet in the solution-treated condition, where the forming is very severe (such as in deep drawing), it will generally be found necessary to anneal. For this operation the sheet must be heated in a forced-air-circulation furnace, at a temperature ranging from 340 to 420°C., a lengthy cooling being necessary if the material is to achieve maximum softness.

Annealing in the salt bath may, on occasions, be resorted to, but this operation necessarily involves quenching in water to prevent the adherence of nitrate. Consequently, the maximum degree of softness is not achieved. This modified annealing operation possesses but a limited advantage over the solution treatment, and thus the practice generally preferred by aircraft manufacturers is to carry out solution treatment only between successive stages of forming.

In this connection, however, it is important that too frequent reheat treatment be avoided in order to prevent excessive grain growth. Alclad sheet, particularly, should be heated for the minimum time compatible with achievement of the necessary mechanical properties. Delay in heating up to the treatment temperature and too prolonged soaking at that temperature may result not only in grain growth, but, due to core diffusion, in reduction of the corrosion resistance of the material.

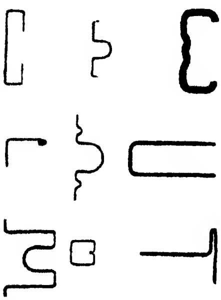
Problems of grain growth are accentuated in the case of aluminium-alloy blanks which have already received a critical amount of cold work. Here, again, the most careful attention must be paid to minimisation of the heating and soaking periods.

As would naturally be expected, such grain growth may frequently be observed in coated sheet in similar circumstances, but if correct procedure has been followed the surface grain growth is, in itself, harmless, It is not indicative of weakness in the core material.

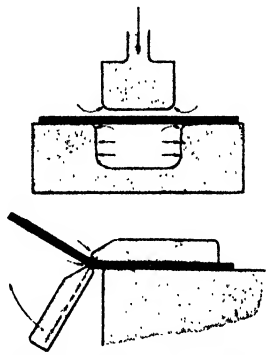
After subjecting the solution-treated material to the usual cold-water quench, it is immersed in a wash tank in order to ensure removal of adhering nitrate. The water in this tank may be either cold or warm, but should not in any case exceed a temperature of 60°C.

Minimising Distortion

The distortion which inevitably occurs during solution treatment may be minimised by quenching in oil or hot water, or cooling in air, but this is attended by the disadvantage that the final mechanical properties are lower than those achieved by cold-water quenching; the material also tends to be somewhat susceptible to intercrystalline corrosion. Normal practice, therefore, is to remove distortion immediately after solution treatment by roll-flattening or stretching, or treating with a mallet of raw hide or rubber before ageing has rendered the material too springy to respond to such persuasion.



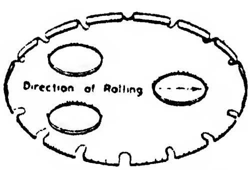
Profiles produced either by rolling or drawing



Bending by simple press operation and in the folding machine respectively is shown in the diagrams. The small arrows indicate where a high polish is necessary

Fig. 43.

Forming of Aluminium Sheet.



The severest forming of flanges is preferably carried out at right angles to the direction of rolling; this should be taken into account when cutting a blank

Forming Operations

With regard to forming operations themselves, probably the most important problems raised are those due to the high coefficient of surface friction of aluminium. Thus, it is essential that a high polish be given to the tools, not only for pressing operations, where the importance of doing so is generally recognised, but also in all other operations involving risk of failure by cracking, dragging or tensional rupture, such as bending, folding and drawing.

In pressing and folding operations it is necessary, at the points of contact, for the metal to thicken up if stretching only is to be avoided. Thus, despite concentrations of pressure, the surface of the sheet must be able to slide freely over that of the tool. The forming surfaces of the latter must, therefore, be given a good finish, whilst, in order to avoid the retarding of motion due to scratches, the tool must be finished in the direction in which the metal is to flow.

In addition to using highly polished tool surfaces, the use of a good-quality lubricant is also essential, the chief requirement of such lubricant, in addition to good lubricating properties, being ability to stand up to the pressures involved. In practice, the materials usually preferred are tallow, beeswax, lard oil and a neutral soap dissolved to the consistency of cream. Cylinder oils of heavy grade are also suitable.

In view of the points raised previously regarding the high coefficient of friction of aluminium, it is of the first importance that the lubricant film be continuous. To avoid risk of "dry spots," which are liable to cause pick-up, the lubricant may be thinned out with a suitable volatile solvent. The evaporation of this solvent from the surface of the blank will leave a continuous film of lubricant on the surface.

It is well recognised that the forming of Alclad sheet may be carried out with less risk of failure than that of an uncoated alloy of similar composition. This is largely due to the fact that properties inherent in the coating and in the zone of transition between coating and core also prevent the initiation of the fine surface cracks which tend to develop on the tension side of bends, and which, by extending, may ultimately cause failure.

Bend Radius

The problem of choosing a bend radius which will avoid any risk of cracking during forming is of considerable importance, the more so as, although the choice of the most liberal radius permissible is well recognised as contributing greatly to ease of fabricating, designers in many cases specify unnecessarily sharp-bend radii without any real reason for so doing. It must be pointed out that failure to observe the need for collaboration between drawing office and works on this matter will inevitably result in trouble in the forming shops and the rejection of an unnecessarily high proportion of components due to cracking at sharp bends.

It is important in all forming operations that the material should conform closely to the profile of the tool, otherwise there is a risk of forming to a sharper radius than that intended. The modulus of elasticity of aluminium, as compared with that of steel, results in a greater degree of spring-back during forming. This must also be allowed for in designing forming tools. The tendency of aluminium alloys to form a peak radius during flattening is also a potential source of cracking, and such tendencies must always be restrained if failures are to be successfully avoided.

Related to the problem of bend radius is the fact that the bending properties of sheet are at their best when the bend axis is at right angles to the direction of rolling. Thus, in a pressed-frame sharper radii may be reliably produced in the flanges at the sides than in those at the top and bottom. So, in cutting the blank for such a pressing, it should be ensured that the direction of rolling is such that the most severe bending will be carried out at right angles to it.

THE RIVETING OF ALUMINIUM AND ITS ALLOYS

Materials for Rivets

RIVETING is the simplest method of joining aluminium and aluminium alloys.

Riveted joints for aluminium are similar to those for steel and other metals with certain slight deviations in design and shop practice due to the properties and characteristics of aluminium and aluminium alloys.

Where the maximum corrosion resistance and weight saving are important, rivets made from various aluminium alloys are used. Steel rivets may, however, be used with aluminium structural work where the joints are painted and kept in good condition to prevent the possibility of electrolytic corrosion. Brass or copper rivets must not be used.

In addition to rivets made from 2S or commercially pure aluminium, rivets of 3S, 16S and 17S alloys are commonly used. The 2S and 3S rivets are made from intermediate tempers of wire or rod stock and are always driven cold in the "as received" condition. High strength aluminium alloy rivets made from annealed 17S wire or rod stock should be driven immediately after heat treatment, this procedure being discussed in detail later.

In order to provide a heat-treated alloy rivet that can be cold driven in the fully heat treated condition, 16S alloy has recently been developed. The cold heading properties of this alloy are superior to those of 17S in the fully heat treated condition, and while it has lower mechanical properties, it has the great advantage of permitting the rivets to be driven in the "as received" condition, thus facilitating assembly work.

Types of Rivets

Below are shown the various types of rivets up to ½ inch (12.7 mm.) diameter as detailed in British Standard Specification 641–1935. In addition to these main types, including modifications of these types used by different manufacturers, there are various types of tubular rivets used chiefly for aircraft work, and the de Bergue rivet described on page 93. The use of the cone type rivet shown on page 88 is also developing for aluminium alloy rivets, this type of rivet having the advantage of requiring only about one-half the pressure to drive as the snap head rivet.

Design of Riveted Joints

With aluminium and its alloys, as with other metals, it is usual to base the design of riveted joints on the shear, bearing and tensile stresses in the rivets and plates and to neglect any frictional resistance between the plates themselves. (The de Bergue rivet is an exception to this rule.) It must always be remembered that rivets are not suitable for applications where a tensile load is placed on the rivet shank or head. For joints which are required to take direct or pulsating tensile loads under service conditions, either bolts with lock washers should be used or the joint redesigned to put the load in shear. This is particularly the case where repeated tensile loads exceed 2 tons per sq. inch (3.150 kg. per sq. mm.). Small tensile loads on rivets are sometimes unavoidable under service conditions and in these instances the type of rivet should be used whose height of head at the circumference of the shank is not less than one-half the shank diameter. Secondly, tensile loads of this kind should be kept to an absolute minimum and should in any case not exceed one-half the safe single shear value of the rivet.

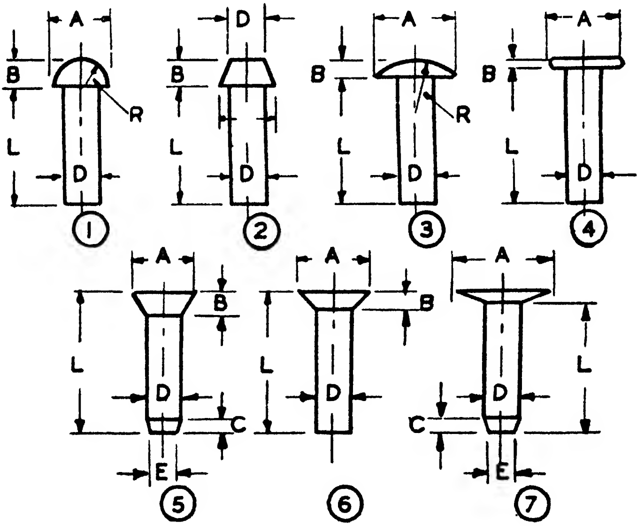


Fig. 44.—Types of Rivet in common use.

In calculating the shearing, bearing and tensile stresses at a riveted joint, it is usual to take the normal diameter of the rivet as a basis. The relation between the rivet diameter, the thickness of the plates and the pitch or spacing of the rivets should be such that the net tensile strength of the plates equals the shearing strength of the rivets. In addition, the diameter of the rivet should, if possible, be such that both the shearing stress of the rivet and the bearing stress of the plate approximate to the allowable safe values. The efficiency of a riveted joint increases as the diameter of the rivet increases and, therefore, the maximum allowable rivet diameter should be used.

Types of Rivets in Common Use

Type.	Diameter of Head A.	Depth of Head B.	Radius of Head R.	Depth of Point C.	Diameter of Point E.
1. Snap (or round) head	1.75D	0.75D	0.885D	—	—
2. Pan head	1.6D	0.7D	—	—	—
3. Mushroom head ..	2.25D	0.5D	1.516D	—	—
4. Flat head	2.0D	0.25D	—	—	—
5. Countersunk head (60°)	1.75D	0.65D	—	0.4D	0.79D
6. Countersunk head (90°)	2.0D	0.5D	—	—	—
7. Countersunk head (140°)	2.75D	—	—	0.4D	0.79D

Compared with riveted steel joints, aluminium structures riveted with aluminium alloy rivets in general require a greater number of rivets of smaller diameter owing to the different ratios between tensile, bearing and shear strengths.

Safe Shear Values of Rivets

The safe shear strength of a rivet in single shear is the cross-sectional area of the rivet shank multiplied by the allowable shearing stress of the rivet material, i.e.

$$F = \frac{\pi \times d^2}{4} \times f_s$$

where F = safe shear value in lbs.
d = diameter of rivet in inches.
f_s = allowable shearing stress in lbs./sq. inch.

TABLE VII

Safe Shearing Design Stresses for Rivets

Table VII gives the safe design stress in shear for 2S, 3S, 16S, and 17S rivets, the values having a factor of safety of 3.5 based on tests on driven rivets. Where specific data on the shearing strength of rivet material is not known, the ultimate shearing

Rivet Material	Safe Shearing Design Stress	
	lbs./sq. inch.	kg./mm.²
2S	3,000	2.109
3S	4,000	2.812
16S	7,000	4.923
17S	10,000	7.036
Steel	13,000	9.131

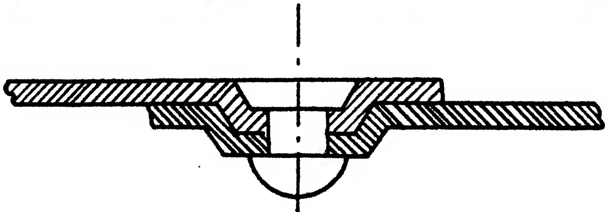


Fig. 45.—De Bergue Rivet *(see page 92.)*

TABLE VIII

Safe Design Value of One Rivet in Single Shear—lbs. and kgs.

Size		2S		3S		16S		17S		Steel	
Ins.	mm.	lbs.	kgs.	lbs.	kgs.	lbs.	kgs.	lbs.	kgs.	lbs.	kgs.
$\frac{1}{16}$	1.588	10	4.5	13	5.9	22	9.9	31	14.1	40	18.1
$\frac{3}{32}$	2.381	21	9.5	28	12.7	49	22.2	70	31.7	90	40.8
$\frac{1}{8}$	3.175	37	16.7	50	22.6	87	39.5	125	56.9	160	72.5
$\frac{5}{32}$	3.969	58	26.3	77	34.9	135	61.3	195	87.9	250	113.3
$\frac{3}{16}$	4.763	84	38.1	115	52.2	195	87.9	280	127.0	360	163.3
$\frac{1}{4}$	6.350	150	68.0	200	90.7	350	158.7	500	226.8	560	294.8
$\frac{5}{16}$	7.938	230	104.3	310	140.6	540	244.9	770	349.3	1,000	453.6
$\frac{3}{8}$	9.525	330	149.7	450	204.1	780	353.8	1,120	508.0	1,450	657.7
$\frac{7}{16}$	11.113	460	208.6	610	272.1	1,070	485.3	1,520	689.4	1,960	883.9
$\frac{1}{2}$	12.700	600	272.1	790	358.3	1,390	629.9	1,980	893.0	2,560	1161.2
$\frac{5}{8}$	15.875	930	421.8	1,240	562.5	2,160	979.7	3,100	1406.1	4,000	1814.4

stress of the rivet may be taken as two-thirds the ultimate tensile strength of sheet of the same alloy.

Table VIII gives the safe design values for various diameters of one rivet in single shear, based on the above stresses. For double shear, the values must be multiplied by two.

TABLE IX

Safe Bearing Design Stresses for Aluminium and Various Alloys.

Alloy and Temper.	Safe Bearing Design Stress, tons/sq. inch, kg./mm.^{2}			
	Tons/sq. inch.	kg./mm.^{2}	Tons/sq. inch	kg./mm.^{2}
2S-O	1.4	2.2	2.2	3.5
*2S-½H	2.5	3.9	3.1	4.9
2S-H	3.6	5.7	4.5	7.1
3S-O	1.6	2.5	3.1	4.9
*3S-½H	2.9	4.6	4.0	6.3
3S-H	4.5	7.1	5.7	9.0
4S-O	2.7	4.3	5.0	7.9
4S-¼H	4.5	7.1	6.3	10.0
4S-½H	5.7	9.0	6.6	10.4
57S-O	3.3	5.2	5.7	9.0
57S-½H	5.7	9.0	7.1	11.3
57S-¾H	5.6	9.0	7.4	12.0
*16S-T	5.6	9.0	8.0	12.6
*17S-T	8.5	13.4	11.6	17.8
24S-T	9.4	14.8	12.9	10.4
51S-Q	5.0	7.9	6.7	19.7
51S-QA	7.1	11.3	9.4	14.8
*Steel	—	—	13.4	21.1

Safe Bearing Values of Rivets and Plates

The safe bearing strength of a rivet or plate is the area in bearing multiplied by the allowable bearing stress of the material, i.e.,

$$P = d \times t \times f$$

where P = safe bearing value in lbs.
d = diameter of rivet in inches.
t = thickness of plate in inches.
f_b = allowable bearing stress in lbs./sq. inch.

Table IX gives the safe design bearing stresses for sheet, plate and extrusions in various alloys and tempers. Two columns are given and it is recommended that the more conservative figures given in column 1 to be used except in cases where detailed information of the bearing loads on the rivets and plates are known and where the plates are laterally fixed by the rivet heads (this is not the case, for instance, where counter-sunk heads are used). The values given in column 2 should also only be used when the edge distance from the centre of the rivet hole to the edge of the plate in the direction of stressing is equal to at least twice the diameter of the hole. For smaller distances the values should be reduced proportionately.

The values given in Table IX opposite an asterisk are the appropriate safe design bearing stresses for rivets made of 2S, 3S, 16S, and 17S alloys and should be used when the rivet is softer than the material through which it is driven, the bearing stress of the rivet material then governing the admissible bearing load.

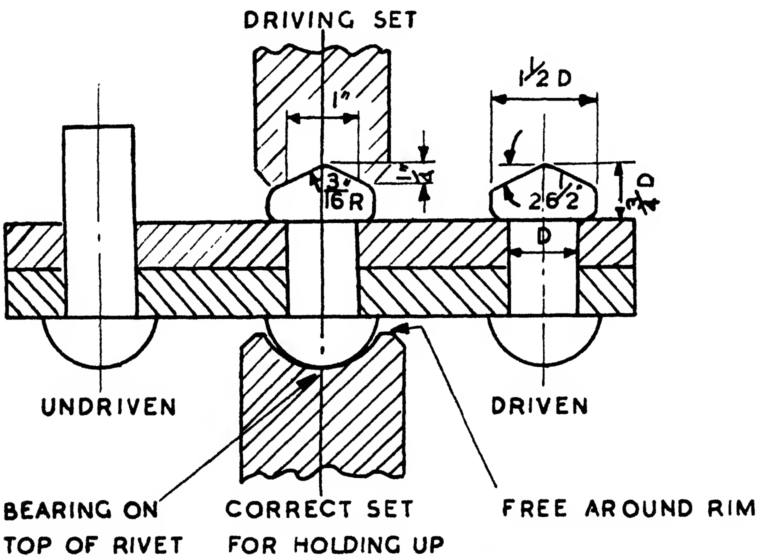


Fig. 46.—*Cone type rivet.* (*See page* 93.)

Diameter of Rivet

If a large rivet is used in thin sheet, there will be an excess of shearing strength over bearing strength and, moreover, there is a danger of the sheet being damaged when the rivet is driven. The nominal diameter of the rivet should therefore rarely exceed 2½ to 3 times the thickness of the outside sheet or plate.

When a small rivet is used in a thick plate, the shear strength of the rivet will be the governing factor and there will be an excess of bearing strength apart from difficulties in fabrication. The rivet diameter should not be less than the thickness of the thickest plate through which it is driven.

Table X gives the size of rivets commonly used for assembling two sheets or plates of equal thickness.

Length of Shank

Where it is essential that the rivet when driven should fill the hole properly, the grip of the rivet should not exceed four times the nominal diameter. The minimum shank length is usually twice the nominal diameter.

The length of shank required to form the head of the rivet, i.e., the length standing proud of the plate surface when the rivet is inserted in the hole and held up tight, depends on the form of head and the clearance between the rivet and rivet hole. For snap head rivets the length required to form the head is about $1\frac{1}{2}$ to $1\frac{3}{4}$ times the diameter of the shank, the total length of the rivet being, of course, this dimension plus the total thickness of the material through which the rivet is driven. It is generally advisable to make several trials with the equipment used on the job before specifying the exact total length required. It is better to have the rivets slightly too long than too short.

TABLE X

Thickness of each Plate.			Diameter of Rivet.	
English Standard Wire Gauge.	Inches	Millimetres.	Inches	Millimetres.
22	.028	.7112	$\frac{1}{16}$	1.588
20	.036	.9144	$\frac{3}{32}$	2.381
18	.048	1.2192	$\frac{1}{8}$	3.175
16	.064	1.626	$\frac{5}{32}$	3.969
14	.080	2.032	$\frac{3}{16}$	4.763
12	.104	2.642	$\frac{3}{16}$ or $\frac{1}{4}$	4.763 or 6.350
10	.128	3.251	$\frac{1}{4}$ or $\frac{5}{16}$	6.350 or 7.938
	$\frac{3}{16}$	4.763	$\frac{3}{8}$	9.525
	$\frac{1}{4}$	6.350	$\frac{7}{16}$ or $\frac{1}{2}$	11.113 or 12.700
	$\frac{5}{16}$	7.938	$\frac{1}{2}$ or $\frac{5}{8}$	12.700 or 15.875
	$\frac{3}{8}$	9.525	$\frac{5}{8}$ or $\frac{3}{4}$	15.875 or 19.050

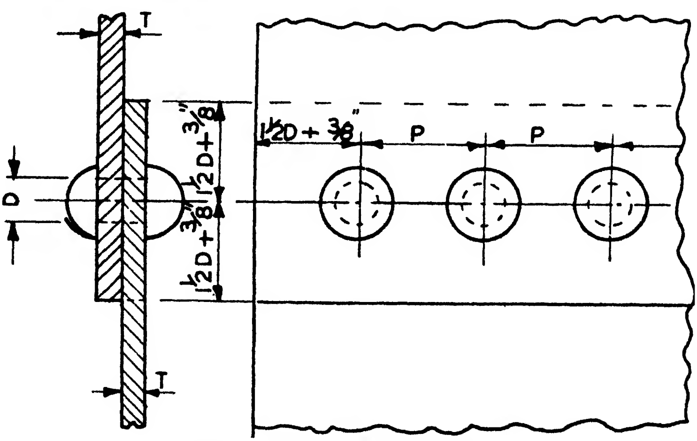


Fig. 47.—Single row lap joint.

Edge Distances

The minimum distance from the centre of any rivet to the edge of the plate or shape should be twice the diameter of the rivet. (Edge distances of $1\frac{1}{2}$ times the diameter

are sometimes used for aircraft work.) A useful rule is to make this edge distance $1\frac{1}{2}$ diameters plus $\frac{3}{8}$ inches (9.525 mm.) for sheared edges or plus $\frac{1}{4}$ inch (6.35 mm.) for other edges. This minimum distance is required in order to protect the edges of the plates or shapes from being sheared or torn off. The maximum distance from the edge of the plate is governed by the necessity of preventing the plate from gaping and should be limited to ten times the thickness of the plate.

Rivet Pitch

For single row lap joints as shown in Fig. 47 the most economical pitch or spacing between rivet centres is about $2\frac{1}{4}$ diameters, but for ease of driving a minimum pitch of 3 diameters is generally required.

Double or multiple row lap joints as shown in Fig. 48 are more efficient than single row joints and should be used when greater strength is required. Either chain or staggered riveting can be used. A pitch of $3\frac{1}{2}$ to 4 diameters is generally adopted with a spacing between rivet rows of $\frac{3}{4}$ of the pitch.

Although lap joints are often used, a butt joint with single or double straps or splice plates as shown in Fig. 49 has the advantage that the plates both lie in the same plane, and when loaded there is no tendency for the plates to buckle. The disadvantage of the butt joint is the increased weight. The estimated efficiency of a butt joint with a single strap is the same as that of a lap joint. If higher mechanical strength is required double straps and double or treble row riveting is adopted, the rivets in this case being in double shear. Single straps on one side of the joint have a thickness the same as the material they join, while with double straps the thickness of each strap is the next gauge greater than one-half the thickness of the parts to be jointed.

The pitch of rivets which have to carry considerable loads should not be greater than six times the diameter in order to ensure that each rivet takes its proper share of the load.

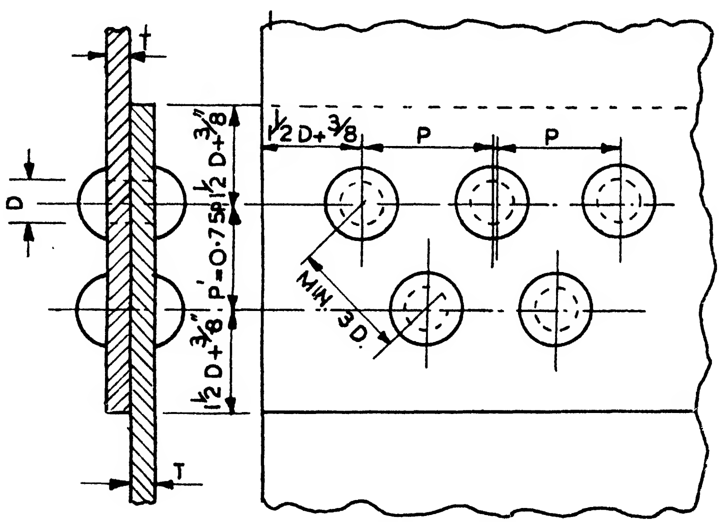


Fig. 48.—Double row lap joint.

When rivets are used merely to hold together two or more plates and the number of rivets is more than ample to take care of any load on the joint, the pitch should be limited to a maximum of twenty-four times the thickness of the thinnest plate. This will prevent the formation of water pockets on the surface of contact of the plates or shapes to be joined.

Care must be taken when designing riveted joints using angles or channels, etc., that the head of the rivet is well clear of fillets and that the driven rivets in one leg of an angle or other shape do not handicap the driving of the rivets in the other leg.

Specifications

The following British Standard or Air Ministry D.T.D. Specifications cover aluminium and aluminium alloy rivets, and the rod and wire for these rivets.

Aircraft Riveting

Specification	Alloy	Minimum Ultimate Tensile Strength	
		Tons/sq. inch	kg./mm.^{2}
L.36	2S	7	11.0
L.37	17S	25	39.4
D.T.D.327	16S	17	26.8

Various types of rivets are used such as the snap head, mushroom head, different forms of tubular rivets and the De Bergue rivet.

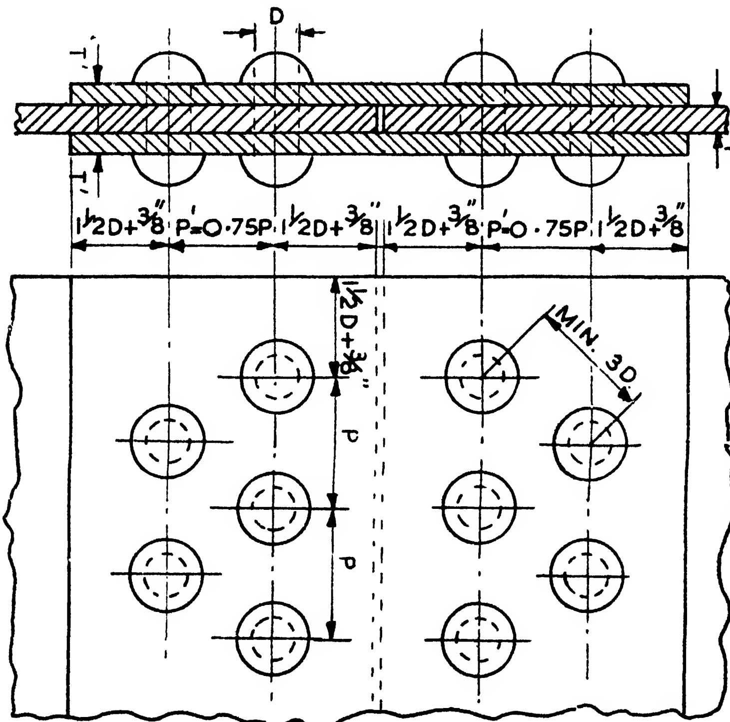


Fig. 49.—*Butt joint with double straps.*

Tubular Rivets

Tubular rivets are often used for thin sheet aircraft construction, and give a higher efficiency than ordinary rivets. The relationship between bearing and shear stresses, the diameter of the rivet and the thickness of the sheet which apply for ordinary rivets, in the heavier sheet gauges, breaks down with sheets below 22 SWG. (.028 inch) (.7112 mm.). Highly stressed riveted joints in thin sheet should be based on the results

of actual tests made, and have to take into account the buckling of the sheet. Since the holding power of the head of tubular rivets is very small, it is even more important with these rivets than with snap head rivets that there should be no tensile loads on the head. There are a number of different types of tubular rivets available, and special riveting machines have been developed for their use.

De Bergue Rivets

The De Bergue patent riveting process has the novel feature that the shear stress is entirely removed from the rivet shank, and is distributed over a considerable surface of the sheets themselves.

The sketch on page 86 shows the section of a joint made by the De Bergue process. Special rivets are used and the holes in the sheets are drilled in the normal way. The rivet is inserted through the hole in the sheets and the original flat rivet head is brought into contact with the flat bottom riveting tool. The top riveting tool, which is specially shaped on its face, descends over the projecting shank of the rivet, and in one operation the flat head is forced flat into the two sheets which sink together into a cup shape formed in the top tool, the sheets remaining dead true. A new cup-head is formed on the rivet shank by means of a cupped depression in the top tool. This type of joint is well suited for thin sheets up to $\frac{1}{16}$ inch (1.588 mm.) thick, and is tight against liquid pressure. It also has the advantage that the outer surface has no projecting rivet head to cause increased air resistance.

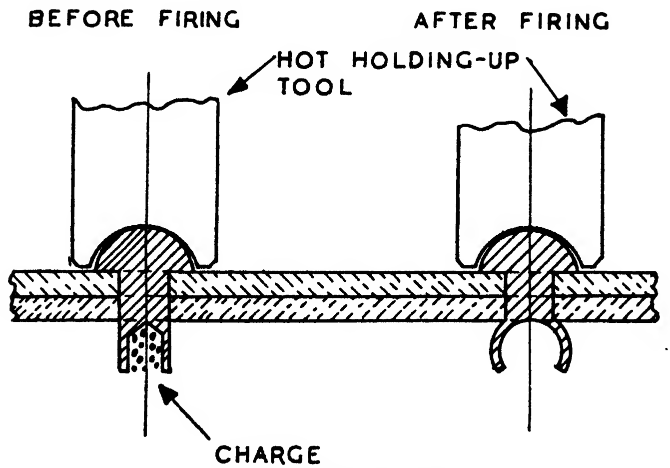


Fig 50.—Explosive rivet

Explosive Rivets

There are many occasions where the design of a riveted article or part is made difficult or more complicated because it is necessary to get to both sides of the rivet for driving. A rivet designed to overcome this difficulty has recently been introduced and relies for its " heading power " on a small explosive charge which is filled into a small hole drilled into the end of an ordinary alloy or steel rivet. The parts being riveted are held together, a rivet is inserted in the hole and an electrically heated holding-up tool which fits the outside head of the rivet and has a silver or aluminium headpiece, is pressed against the rivet head. Heat is conducted through the rivet to the charge, which fires when it reaches a temperature of 130°C.

The explosion blows out the side of the hole to form a cup-shaped head as shown in the sketch above. The time required to heat through a rivet is, usually, 1–5 seconds, depending on the size of the rivet, the larger being given an anodic coating to insulate it and prevent loss of heat in the parts being riveted.

It is claimed that the explosive is non-corrosive and that in the case of 17S rivets, the strength is about 85% that of ordinary rivets. With this type of driving, the rivets would be used in the fully heat-treated condition and the expense and trouble of heat-treatment immediately before driving is eliminated.

Cone Head Rivets

A new type of rivet head, known as the "cone" head, has been recently developed for aluminium alloys, which has the advantage of being cold driven with almost half the pressure required for snap heads. The cone head, and the sets to drive it, are shown on page 88. This type of head, in addition to requiring less power to drive or squeeze it, gives a rivet of strength equal to the usual types, requires a shorter length of shank for forming the head, and entails less danger of the heads being brittle and breaking off. Also one size of rivet set will suffice in heading several different diameters of rivets.

Punch Countersunk Rivets

Ordinary counter-sinking is obviously unsuitable where a comparatively thin sheet of aluminium is being riveted to material of a thicker section, and where a flat surface is required on the thin sheet side of the joint. In such cases a method of Punch counter-sinking illustrated in the sketch on this page is employed. As is shown, the hole in the thicker material is countersunk in the usual way, but in this case, on the surface facing the sheet. The thinner sheet metal is then punched into the countersink so formed. The rivet used has a countersunk head which slightly overfills the depression and the rivet is headed on the inside. This method of riveting considerably increases the shear strength of the joint. The tendency for rivet holes to get out of coincidence while the rivets are being driven is to a very great extent overcome by this method of riveting.

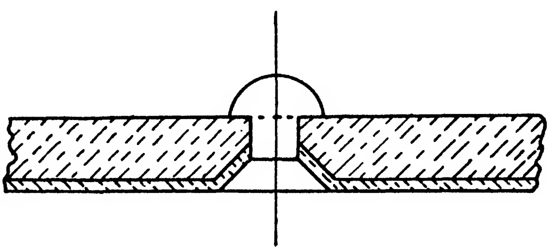


Fig. 51.—*Riveting Alclad* (*see page* 94.)

TABLE XI

Pressure in Tons required to drive Snap or Round Head Rivets with Squeeze Riveter.

Size.		Alloy Cold Driven.				Alloy Hot Driven.		
Inches.	mm.	2S	3S	16S 55S	17S*	16S 55S	17S	Steel.
$\frac{1}{4}$	6.350	6	7	8	10	—	—	10
$\frac{3}{8}$	9.525	14	15	18	24	13	18	17
$\frac{1}{2}$	12.700	25	27	32	42	22	30	25
$\frac{5}{8}$	15.875	36	39	54	64	31	43	32
$\frac{3}{4}$	19.050	49	53	80	—	42	58	40
$\frac{7}{8}$	22.225	65	70	—	—	54	73	48
1	25.400	—	—	—	—	66	89	57

* Driven immediately after quenching.

Cone Head Rivets require about half these pressures.

RIVETING "ALCLAD"

"Alclad" sheet is riveted with heat-treated alloy rivets, and the high purity aluminium coating on each side of the sheet electrolytically protects the heads of the rivets against corrosion, as it does the cut edges of the sheet. In addition, the soft high purity aluminium acts as a gasket under the head of the rivet and prevents the corrosive medium from penetrating between the rivet head and the sheet. "Alclad" 17S-T and "Alclad" 24S-T sheet, due to its exceptional corrosion resistance, is universally used for flying boat hull and seaplane float construction. For water-tight spacing, a pitch of 3½ to 4 diameters is often adopted with a distance between rows of 2 diameters, and an edge distance of 1½ to 2 diameters of the rivets used.

Selection of Rivet Alloy

Riveting practice in aluminium alloy construction differs slightly from that used in steel construction. As a general rule it is advisable to use rivets of about the same properties as the alloy to be joined. The choice of the correct rivet material is, however, influenced by a number of factors, and each application should be considered on its own. The following combinations of structure and rivets have been found to work together very satisfactorily.

Alloy Structure.	Rivet.
2S	2S
3S, 4S, 57S annealed	3S
3S, 4S, 57S quarter-hard or harder	3S, 16S
17S-T, 24S-T	16S, 17S, Steel
"Alclad" 17S-T, "Alclad" 24S-T	16S, 17S
51S-W, 51S-T	16S, Steel

Steel or soft iron rivets should only be used when the finished structure is thoroughly painted and maintained, since rust stains are likely to mar the appearance if the bare steel is exposed. Properly protected steel rivets driven in freshly painted holes are satisfactory in many types of aluminium construction.

Cold Driven Aluminium Rivets

Wherever possible aluminium alloy rivets are driven cold. Rivets made from 2S, 3S and 16S alloys are driven in the "as received" condition.

Rivets of 17S alloy should always be heat-treated before driving to produce the maximum properties in the finished rivet. The heat-treatment consists of holding the rivets at a temperature of 480°–500°C in a fused nitrate bath or air furnace for about ten minutes, and then quenching them quickly in cold water.

The rivets should be thoroughly washed to free them from nitrate and driven within half-an-hour after quenching. The rivets then age harden spontaneously, attaining their full properties after four days. If they are allowed to age harden before driving for more than one hour after quenching, they become too hard to drive easily without cracking, and must be reheat-treated. The age hardening effect can be retarded by storing the rivets in air at 0°C immediately after quenching, when they will remain soft enough to drive for 24–36 hours. By using solid carbon dioxide, much lower storing temperatures can be maintained, and the driving period prolonged almost indefinitely.

Hot Driven Aluminium Rivets

The larger sizes of 17S such as ½ inch (12.7 mm.) diameter and over are generally driven hot after heating to 480°–500°C.

The quench is obtained by contact with the cold driving tools and cold plate metal. It is important that hot driven 17S rivets be transferred from the furnace and driven with a minimum lapse of time. The larger sizes of 16S rivets are sometimes driven hot.

Hot Driven Steel Rivets

Steel rivets in aluminium alloy construction are driven hot in the usual way. They are heated to about 1,000°C, and driven with as little delay as possible, as the high heat conductivity of aluminium alloys tends to cool the rivets more rapidly.

Riveting Equipment

In order to fill the rivet hole properly and to form a good head, it is essential that aluminium rivets be driven with a few heavy blows. A light hammering action tends merely to peen the head of the rivet, which hardens up quickly, and the shank of the rivet is not properly upset so as to fill the hole completely. It is important that the rivet sets should have smooth polished surfaces, so that the metal may flow readily during the forming of the head.

Small aluminium alloy rivets can be driven by hand, using a larger hammer than for the same size of steel rivet, and a heavy dolly which bears on the rivet head and is slightly greater in diameter than the rivet head.

Squeeze riveters are the most satisfactory type for driving aluminium alloy rivets. One shot riveting hammers are often used when rivets cannot be driven with a squeeze riveter. Pneumatic riveting hammers when used should generally be larger than those required for steel rivets. In some cases light pneumatic rotating hammers are used with rivet snaps, having a cross-shaped portion in relief on the striking surface. This design, though allowing a large number of partial impacts to be made, avoids the tendency, when using light hammers, for the end of the rivet to harden up before the head is formed.

Recommended Driving Pressures

Care must be taken that the pressure applied to drive a rivet is not so great as to crush the plate causing it to flow and the edge to become wavy. The pressure required varies roughly as the square of the diameter of the finished driven head, so that a small size head has a considerable advantage over a large one. Table XI gives the approximate pressure required to drive full snap heads with a squeeze riveter. Pressure about two-thirds those given will produce heads complete enough for some work.

Rivet Holes

Rivet holes must be drilled or sub-punched and reamed to size. Standard twist drills are suitable, but drills with flutes with a greater spiral angle, i.e., with more twists per inch, are specially satisfactory. Reamers should preferably be of the spiral fluted type. Paraffin, or a soluble cutting oil, is a suitable lubricant.

The clearance to allow in the holes should be the smallest possible that will allow the rivet to be inserted easily without delay. The smaller the clearance the better will be the job of driving the rivet head, but the greater coefficient of expansion of aluminium than of steel must not be overlooked when driving hot aluminium alloy rivets.

Assembling Riveted Joints

When riveting aluminium, especially the softer alloys, the metal tends to flow, causing the rivet holes to get out of coincidence if the work is not carefully done. For this reason riveted structures should have all parts properly aligned and firmly drawn together by bolts distributed along the joint, before riveting starts. The bolts should be well tightened to prevent slipping and also to prevent the rivet shanks from squeezing out between the parts of the joint during the driving operation. When riveting long rows the rivets should be driven at random, instead of progressively from one end to the other.

It is recommended strongly that all material be thoroughly cleaned and painted with one coat of paint before riveting is started. Zinc chromate primers, bitumastic paints, or "Noral" aluminium paint mixed with a bitumastic medium are especially suitable. The paint should be allowed to dry before assembly. Rivets should be driven into freshly painted rivet holes. This practice should also be followed with hot driven rivets, although the hot rivet will impair somewhat the waterproofing effect of the paint in the rivet holes.

THE WELDING OF ALUMINIUM AND ITS ALLOYS

THE welding of aluminium and its alloys may be divided into the following three main classifications :—

(1) Fusion or autogeneous welding, using oxy-acetylene, oxy-hydrogen or oxy-propane flames, as on fuel and oil tanks for aircraft.
(2) Electric arc fusion welding, including the metallic arc, carbon arc and atomic hydrogen arc welding processes, also applicable to fuel and oil tanks.
(3) Electric resistance welding, including butt, spot and seam welding.

Spot welding is specially suitable for the heat-treated aircraft alloys in sheet, strip and extruded section form, and is widely used for mass production items. Seam welding applications are found in fuel and oil tanks. Butt welding has proved successful for conductor wire and rod, and for assembling window sections, etc.

Fusion Welding

The oxy-acetylene or oxy-hydrogen blow-pipe is the most widely used method and is applicable to butt, lap, tee and fillet joints in the same manner as with any other metal. The technique differs slightly from that used with steel or other metals, but is easy to acquire and welds can be made by this method on sheet, extruded sections and castings.

The chief points to be remembered when welding aluminium and its alloys are as follow :—

A highly refractory oxide film forms on aluminium immediately it is exposed to air and the removal of this film is essential before a satisfactory weld can be made ; aluminium has a high rate of expansion and contraction approximately twice that of steel, and due allowance has to be made for this ; aluminium and its alloys have high thermal conductivity, high specific heat and a relatively low melting point and in general are weak in tension at temperatures just below the melting point.

Welding Apparatus

Suitable blow-pipes and equipment for welding aluminium and its alloys by the oxy-hydrogen or oxy-acetylene method are manufactured by a number of companies. The selection of the correct size of tip or nozzle for any particular work is largely a matter of experience. The size of the tip depends on the shape and size of the object to be welded, as well as upon the thickness, since the larger articles have a greater capacity for heat and a larger radiating surface. A larger tip is used for hydrogen than for acetylene on any given gauge of sheet.

Recently there has been placed on the market a propane fuel gas sold under the trade name of Propagas. It is packed in portable steel bottles weighing 58 lbs. (26.31 kgs.) each when full and containing 23 lbs. (10.42 kgs.) of liquid, equivalent to nearly 200 cubic feet (5.66 cubic metres) of gas. Propagas has a calorific value of about 2,400 B.Th.U.s per cubic foot (84,754 B.Th.U.s per cubic metre), compared with about 1,500 B.Th.U.s per cubic foot (52,971 B.Th.U.s per cubic mètre) for acetylene. The temperature of the oxy-propane flame is lower than that of the oxy-acetylene flame, the former being about 2,500°C. while the latter is as high as 3,400°C. Advantage is taken of this feature for the welding of low melting-point metals, such as aluminium. During the welding of light gauge sheets the tendency for the metal to run into holes is minimised and the work is more easily controlled.

Propagas may be used in standard types of acetylene welding blow-pipes, although it is better to use the special types manufactured and suited for this gas.

The technique of welding is very similar whichever gas is used, and an operator accustomed to one type of welding should have no difficulty with the other.

Flame Adjustment

It is general practice to use the oxy-acetylene flame in preference to the oxy-hydrogen flame, since the former as a rule gives sounder and more ductile welds. The oxy-hydrogen flame will, however, produce satisfactory joints with metal up to ¼ inch (6.35 mm.) in thickness, but does not supply sufficient heat for welding metal of greater thickness.

When using hydrogen, acetylene or propane the blow-pipe should be kept scrupulously clean and should be carefully adjusted to show a neutral flame, since this gives the best speed and economy, as well as a cleaner and sounder weld. A faulty or dirty tip will give indifferent results, and the tip should be cleaned frequently by blowing it out from the inside and not by pushing a needle through from the outside.

The oxy-hydrogen flame is neutral when the volumes of the two gases issuing from the tip of the torch are balanced. With an excess of oxygen the flame will be rather small and will have a very short cone at the tip of the blow-pipe. With an excess of hydrogen the flame is long and ragged and there is no well-defined cone at the centre. The neutral flame in which the mixture of the two gases is properly balanced is a well-defined jet or blue cone in the centre of the large flame.

A wide variety of flame conditions is possible with acetylene by different adjustments of the blow-pipe. A neutral flame is secured by reducing the amount of acetylene only until one white cone is visible. Outside of this cone is a nearly colourless flame of large volume. The neutral flame is not only the hottest, but it also prevents excessive oxidation of the molten metals by providing a reducing gas envelope. Any excess of oxygen should be carefully avoided. A slight excess of acetylene is satisfactory.

To readjust the welding flame under practical conditions it is best to increase the stream of acetylene until two cones appear and then decrease it until only one cone is visible.

Welding Flux

In order to remove the oxide film from the surface of the metal a suitable flux is nearly always employed. Mechanical methods, such as the "puddling" system, are sometimes used, in which steel tools break up the film and allow the metal to coalesce, but joints made in this manner without the use of flux nearly always contain a certain amount of oxide, resulting in loss of strength, and it is especially recommended that fluxes be employed. The importance of using a good quality flux cannot be too highly stressed. A satisfactory flux both dissolves the oxide on the surface of the metal and prevents further oxidation taking place during the welding operation.

Fluxes are most frequently mixtures of alkaline halides or sulphates such as fluorides, chlorides, sulphates or bisulphates of sodium, potassium and lithium, and often contain cryolite - a double fluoride of aluminium and sodium.

There are a number of good fluxes on the market among which may be mentioned Aluminium Union Limited No. 22 Welding Flux, the British Oxygen Company's "Alda" Standard Specification, "Alda" Air Ministry D.T.D. 119 Specification Flux, and Laffittium.

The flux can be used mixed with water to the consistency of a thin paste, or more often the flux is used dry; the welding rod, after being heated, is dipped into the dry flux, which adheres to it, and the flux is then melted up the rod to form a thin varnish. The gradual melting of the rod as the welding progresses automatieally feeds flux on to the weld at the position where it is required. In cases where no welding rod is used, as with certain flanged joints, the flux in paste form may be applied to the seam to be welded by means of a brush. The use of excess flux is to be avoided.

Any flux used in paste form should not be used again after standing overnight as its composition is thereby modified and its fluidity and consistency impaired. The fluxes are hygroscopic and must be kept in a dry place in tightly fitting containers. It is extremely important that all traces of flux should be removed after the weld is complete, and full details regarding this are given on page 103.

Selection of Welding Wire

The choice of the correct welding rod or wire is of great importance. If welding pure aluminium (2S) sheet or plate the welding rod or wire should preferably consist of the same material. For the aluminium-manganese alloy (3S) either pure aluminium or 3S welding rod should be used. The heat-treated alloys 13S, 17S and 51S can most easily be welded by using a 5% Silicon welding rod (33S), though, where no stresses are placed on the metal while cooling and where the parts are free "to come and go" due to expansion and contraction, then a sounder weld can be made if a welding rod of the same composition as the parent metal be used. The latter method helps to prevent discolouration at the weld if the article is subsequently anodised. For certain difficult jobs a 10% silicon welding rod is used on account of the high fluidity of this alloy. Owing to its short solidification range, however, particular care is necessary with this alloy.

The success of the 5% silicon welding rod may be attributed to the relative freedom from hot shortness of this alloy, combined with good corrosion resistance and high strength. It also has a lower melting point and a wider melting range than pure aluminium and thus fills in the voids raised by the solidification shrinkage of the welded parts in the same way that a "gate" fills in the shrinkage of a casting.

One caution should be remembered in the use of aluminium-silicon welding rods when the articles are to be subjected to solution heat-treatment after welding. The introduction of an appreciable amount of silicon into the weld lowers the safe temperature to which come of the strong alloys may be heated, so that none of these alloys should then be heated above 500°C.

The Table given on page 99 summarises the recommended welding rod for various alloys.

Welding wire and rod is usually supplied in $\frac{1}{16}$ inch (1.588 mm.), $\frac{1}{8}$ inch (3.175 mm.), $\frac{3}{16}$ inch (4.763 mm.), $\frac{1}{4}$ inch (6.35 mm.) and $\frac{5}{16}$ inch (7.938 mm.) diameter sizes and the size of the rod should be chosen to be approximately equal to or slightly greater than the thickness of the metal to be welded. Ordinarily $\frac{1}{8}$ inch (3.175 mm.) diameter rod is suitable for welding any thickness of metal up to $\frac{1}{8}$ inch (3.175 mm.) and $\frac{3}{16}$ inch (4.763 mm.) diameter rod may be used for heavier gauges. Even for very thick section rods over $\frac{5}{16}$ inch (7.938 mm.) diameter are rarely used. In many cases where welding rod of the correct composition is not available, scrap pieces from the material to be welded may be used.

Fig. 52.—Preparation for Welding.

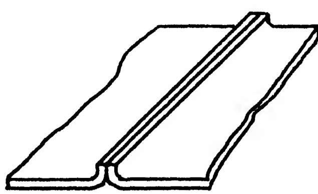


FIG. 52A

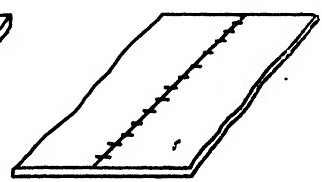


FIG. 52B

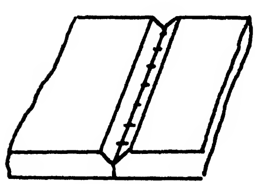


FIG. 52C

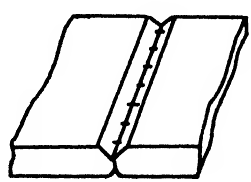


FIG. 52D

Preparing Aluminium for Welding

The preparation of metal for welding affects very considerably both the quality of the weld and the cost. Cleanliness of the edges to be welded is of extreme importance; any trace of lubricant or grease must be removed before welding commences. A satisfactory method of degreasing is by means of petrol, followed by rinsing in a 5% to 10% caustic solution, neutralising with a 5% to 10% nitric or sulphuric acid solution, followed by washing. A further cleaning of the edges should then be carried out by the use of a wire brush or sand blasting. For light gauge sheet (.048 inch, 1.219 mm., and lighter) the edges may be flanged to an angle of 90° as shown in Fig. 52A, the height of the flange being about one-and-a-half times the thickness of the metal. Welding wire or rod is then unnecessary, since the melting of the edges provides the necessary material for the weld. Butt welds in heavier gauge sheet up to $\frac{1}{8}$ inch (3.175 mm.) thick can best be made by butting the edges together and cutting notches with a cold chisel, as shown in Fig. 52B, the notches being about as deep as the thickness of the metal and about $\frac{1}{8}$ inch (3·175 mm.) apart.

Welding Rod and Wire		
N.A. Alloys to be welded	Welding rod for material thicker than 1/16″. In general no welding rod is necessarv for thicknesses under 1/16″ (1.588 mm.).	Remarks
Wrought Alloys		
2S	2S	
3S	2S	3S wire may also be used.
4S and 57S	2S	When surface finish is less important, 5% Silicon is recommended.
13S and 51S	5% Silicon (33S)	If the joint has to be anodised, 2S, 13S or 51S wire is recommended; where subsequent heat-treatment is performed, 13S or 51S wire should be used.
17S	5% Silicon (33S)	When subsequent heat-treatment is performed, use 17S wire. Use spot or seam welding wherever possible.
Casting Alloys		
123	5% Silicon (33S)	123 alloy contains 5% Silicon.
125	5% Silicon (33S)	May also be welded with 125 alloy rod.
135	5% Silicon (33S)	May also be welded with 135 alloy rod.
162	5% Silicon (33S)	12% Silicon is frequently used, but is less satisfactory than 5% Silicon.
225	5% Silicon (33S)	225 alloy rod is not recommended.
350	5% Silicon (33S)	350 alloy rod is not recommended.

For heavy material the edges should be bevelled to form a 90° vee. The vee should not extend through the entire thickness of the material but a lip of between 1/16 inch (1.588 mm.) and 1/8 inch (3.175 mm.) should be left as shown in Fig. 52C. The lip should preferably be notched before welding.

Material above 1/2 inch (12.7 mm.) thick can best be welded by bevelling both sides as shown in Fig. 52D.

For sheets from 1/16 inch (1.588 mm.) to 3/16 inch (4.763 mm.) thick one blow-pipe is generally used, with the sheet arranged in a horizontal plane, the power of the blow-pipe ranging from 2 1/2 (70,792 cubic cm.) to 8 cubic feet (226,536 cubic cm.) of acetylene per hour. For sheet thicknesses above 3/16 inch (4.763 mm.) however, it is often an advantage to have two operators and to work in a vertical plane, the combined power of both blow-pipes ranging from 4 (113,268 cubic cm.) to 11 cubic feet (311,487 cubic cm.) of acetylene per hour for 3/16 inch (4.763 mm.) and 3/8 inch (9.525 mm.) thick sheets respectively. The advantage of having two operators is that a considerably smaller blow-pipe tip is used and a better quality weld results.

The metal should be supported so that the underside of the weld is free, in order that the added thickness of metal in the weld may form a slight bulge on the under surface, which can afterwards be dressed down if desired.

For production welding the use of simple jigs and fixtures increases the speed of welding and tends to overcome distortion in the finished product.

Effects of Expansion and Contraction

Due to the relatively high coefficient of expansion of aluminium (.000024 inch per inch per degree Centigrade), which is about twice that of iron, precautions are necessary to avoid buckling in the finished sheet. The metal will expand around the portion heated by the flame and after the weld is complete will contract again on cooling, and the work must be arranged so that this expansion and contraction can take place freely. In certain cases buckling cannot be avoided in welding plate and sheet, but these buckles can generally be straightened out by hammering after welding. For this reason, it is a wise provision in welding sheet aluminium to locate the joints in positions where they can be backed up on either side during the hammering operation. For

instance, it is best, when possible, to avoid making a weld where two sheets come together at an angle. This can be accomplished by turning up a flange in one of the sheets and making the weld at least 1½ inches (38.1 mm.) from the corner. The turned-up flange will stiffen one of the sheets so that it will not warp, and any slight buckle in the other sheet can be readily removed by hammering.

Pre-Heating

Aluminium sheet ⅜ inch (9.525 mm.) or more in thickness and the larger aluminium castings should be pre-heated to 370°C. or 430°C. in order to avoid heat strains and to reduce the amount of oxygen and acetylene required for the actual melting of the seam. By pre-heating the risk of distortion is also reduced.

It is important that the pre-heating temperature does not exceed the upper limit of 430°C.

If pyrometers are not available, one of the following methods may be used for determining the proper pre-heating temperature :--

(1) At the proper temperature for welding a pine stick rubbed on a casting will leave a charmark on it.

(2) Chalk marks, made with carpenter's blue chalk, will turn white at the proper temperature for welding.

(3) Cold aluminium gives a metallic sound when struck which becomes duller as the temperature is raised. At the temperature required for welding there is no longer a metallic ring.

As a welder becomes experienced in handling aluminium, he will at times be able to use a low-temperature oil or gas torch for partial pre-heating. In this case, the pre-heating is done locally along the seam, just ahead of the welding flame, so that the welding heat will not bring on too sudden a rise in temperature and cause cracking.

Blow-Pipe Manipulation

The speed of working in welding aluminium is greater than in the welding of steel, and the movement along the seam becomes more rapid as the metal becomes heated.

The welding rod is held loosely in the fingers, and is kept in a direct line with the weld. The blow-pipe flame is held so that it will melt simultaneously both edges of the sheet or casting and the end of the welding rod.

It is also important, when starting, that the two edges should commence to mell before any filling material is melted.

If the blow-pipe is kept at an angle of about 30° to the surface being welded, it will prevent too rapid melting of the material in a restricted area. By holding the blow-pipe at such an angle the outer cone of the flame will envelop the metal well ahead of the point of welding, and welding will progress more rapidly.

A very slight backward and forward movement of the welding rod along the direction of welding assists the flux to break down the oxide film and results in better penetration. It is essential that the welding rod be fed evenly to the work; especially does this become of importance when welding the thinner gauges of sheet.

Fig. 53 shows the recommended position of blow-pipe, welding rod and edges to be welded. Care must be taken that the weld penetrates the full thickness of the sheet, leaving a small projection on the underside of the sheet.

The blow-pipe must not of course be stopped in any one position too long or holes will be made in the sheet; neither should the inner cone of the flame be allowed to come into contact with the metal. The operator should watch the metal carefully for signs of melting, and fuse the welding rod metal thoroughly with the molten metal of the sheet or casting.

Welding Pure Aluminium or Aluminium Alloy Sheet

The parts are assembled before welding, in much the same way as welding steel sheet. The sheets are welded with the edges butted together, there being no advantage in having a double seam with overlapping edges. Long seams should be tack welded progressively from end to end at intervals of two to four inches. Irregular tack welding produces an unsightly weld and is likely to cause cracks. After tacking, the flame of the blow-pipe is played upon both edges of the sheet simultaneously, causing them to melt; and, the oxide being removed by the flux, the molten edges flow together and join. The weld should not be started at the edge of the sheet. Start it a few inches back and weld toward the edge and then go back and continue along

the seam, only a small part of the metal being welded at one time, and the tacking being thoroughly melted again when welding through. The weld should be built up slightly above the surface of the base metal, and the thoroughness of penetration will be apparent when there is a small projection formed evenly along the length of the weld on the underside of the joint. The welding operation should be completed as rapidly as is consistent with good workmanship. In welding long seams, if pronounced buckling of the metal occurs it should be straightened out by hammering before proceeding further with the welding.

The heat-treated alloys are somewhat more difficult to weld than the work-hardened alloys, and there is a relatively greater decrease in strength at or near the weld, unless the sheet can subsequently be heat-treated. Very satisfactory welds, however, have been made with 13S, 51S and 55S alloys, using either 5% silicon welding rods, or metal of the same composition as the parent metal. Although 17S alloy can be welded satisfactorily, it is difficult to avoid contraction strains with this alloy.

In all blow-pipe welding of aluminium heat-treated alloys, it is extremely important to do the job as quickly as possible in order to minimise the amount of over-heating and annealing

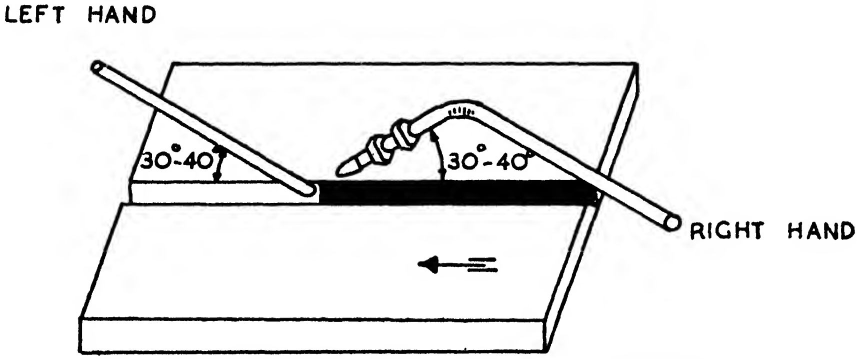


Fig. 53.—Recommended position of blow-pipe and welding rod.

Welding Extruded Sections, Tubing and Wire

When welding extruded sections and tubing, the same general instructions should be followed as for sheet. Tack welds should be made and then the edges welded together from the inside towards the outside. In Fig. 54, which illustrates the position and direction of butt welds on various sections and tubing, the preliminary tack welds are shown shaded and subsequent welding is carried out in the order and in the direction shown by the arrows. It is important that the insides of hollow sections and tubing be kept accessible so that all traces of flux can be washed away after welding.

When two pieces of wire or rod have to be welded, the two ends are heated slightly, dipped in flux and butted together in the flame, using a uniform, moderate pressure, so as to leave a small ring or " flash " around the joint. The flame is then removed, the pressure being continued for a few seconds longer. The ends of the wire or rod can conveniently be rested on a refractory brick in which a depression has been cut to receive the flash. This flash is afterwards cut off with sharp wire cutters. Larger sizes of wire or rod can best be welded electrically by the butt resistance method described on page 108.

Strength of Welds

When the joint is completed every portion of the seam will have been melted and solidified again, hence the metal in the weld is in the cast state. Thus, hard rolled sheets, after welding, will exhibit three zones :—

(1) Region of cast structure at the weld.
(2) Region of partially annealed material on both sides of the weld.
(3) Region of material unaffected by the heat of welding.

Independent, therefore, of the temper of the original sheet, the strength near the weld will be approximately that of the fully annealed metal. Any lowering of properties

caused by the cast structure at the weld may be overcome by increasing the thickness of the sheet by the addition of welding rod. In general, weld joints when tested under tension will not fail at the actual weld itself, but about 1 inch (25.4 mm.) from the weld in the region of annealed material.

With the heat-treated alloys, however, the area on either side of the weld is not completely annealed, and the joints when tested in tension may fail at the weld itself, due to the strength of the cast weld zone in these alloys being lower than the partially annealed material adjoining the weld. The fact that with the heat-treated alloys failure under tension occurs at the weld itself, does not mean that the welds in these

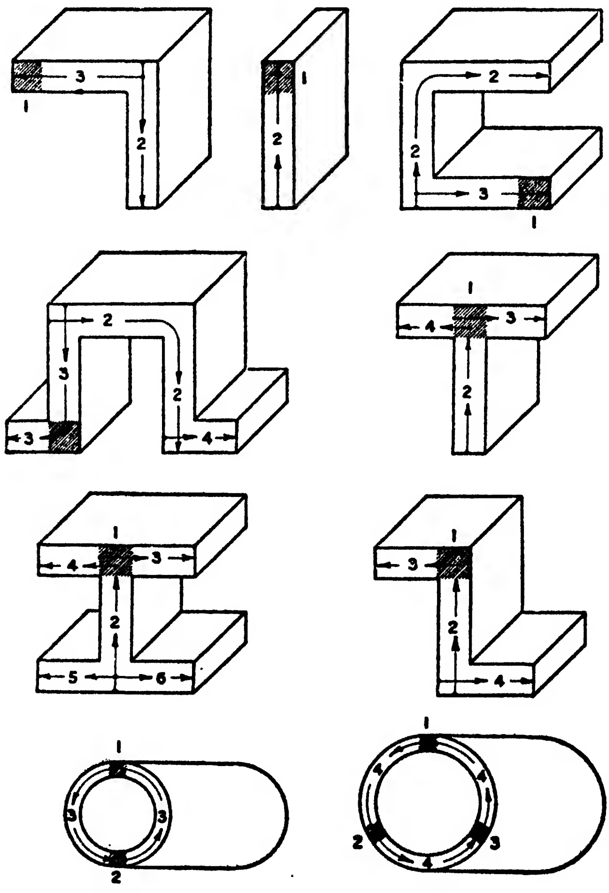


Fig. 54.—Position and direction of butt welds on various sections and tubes. Jack welds are shown shaded, and subsequent welding is done in order and direction of arrows.

alloys are less strong than in 2S or 3S metal. Actually the strength in the region of cast structure at the weld with the heat-treated alloys is generally higher than the strength of the annealed metal near the weld, in the case of the non-heat-treated alloys.

Finishing Welds

As soon as the weld is completed and the work has had time to cool, it should be thoroughly washed to remove all traces of flux, since the flux is by nature corrosive

to the metal. It should be remembered that small repeated washings are more effective in removing the last traces of flux than one large wash. The washing should be carried out within a few hours after welding and before any hammering is done. Thorough cleaning by means of hot water and a brush is not enough to remove flux from the smaller crevices. A very successful scheme for removing the flux is to wash welds first in hot water, and then in a hot 5% solution of nitric acid or 10% solution of sulphuric acid, the acid solution being afterwards washed off with clean hot water. Testing with an acidified 2% silver nitrate solution will determine the efficiency of the operation with the fluxes mentioned above. If a heavy white precipitate is formed when a drop of the silver nitrate solution is placed on the joint to be tested, the cleansing has been insufficient and the washing should be repeated.

When it is desirable to remove all traces of the weld, the greater portion of the excess metal may be chipped off with a chisel, dipping the cutting edge of the chisel frequently in light oil to prevent chips of aluminium sticking to it. The joint can then be ground smooth, using a felt bob dressed with No. 60 or No. 90 emery at a surface speed of around 4,800 feet (1,463.04 m.) per minute. For specially smooth finishes a second bob dressed with No. 120 emery should then be used, followed by a polishing buff treated with tripoli, using a surface speed of around 8,000 feet (2,338.4 m.) per minute.

It is sometimes the practice to finish welds in pure aluminium (2S) and the aluminium manganese alloy (3S) by hammering. This process can be recommended particularly in chemical, dairy or other equipment, requiring a smooth surface, as well as maximum strength in the weld area. The hammering obliterates any surface porosity, releases stresses due to cooling, eliminates the cast structure and produces a harder metal. Hot hammering at a temperature between 300 and 400°C. is sometimes employed, but it is more usual to adopt cold hammering. Annealing after cold hammering is also sometimes used, in order to obtain a ductile weld, the annealing being carried out with a torch at a temperature between 300 and 350°C. : it is recommended that the annealing temperature should not exceed 400°C. Hammering is done on the aluminium alloys by first chipping the irregular edges off the weld bead and then beating the bead down over a heavy back up piece to the same thickness as the metal on each side of the weld. Sufficiently heavy blows should be used to work the metal throughout the cross-section and not merely to peen the surface.

Some of the heat-treated alloys are more sensitive to cracking under hammering than 2S or 3S. Such welds can be hammered without cracking, but in the chipping process before hammering the weld bead must be cut down further than with 2S and 3S metal. In general, hammered w lds are not recommended with heat-treated alloys.

Anodic Treatment of Welds

Owing to the sensitivity of the anodising process to difference in crystalline structure as well as to difference in composition between the base metal and the weld metal, it is difficult to avoid slight discolouration at the weld when the joints are anodised. This discolouration, while it may be somewhat disfiguring on ornamental work, nevertheless has no detrimental effect on the protective properties of the anodic film.

In general, therefore, it is advisable to avoid weld joints wherever possible in cases where a perfectly uniform finish is required after anodising. Discolouration may, however, be reduced to a minimum by the following precautions :—

Firstly, the welding rod or wire must be of the same composition as the parent metal (5% silicon welding rod produces a grey colour after anodising). Secondly, the importance of a thorough cleaning after welding cannot be overstressed where a joint is subsequently to be anodised, and attention is drawn to the recommendations given above. Thirdly, the weld should be hammered flat after thorough washing and before finishing and polishing so as to break up the cast structure at the weld and approximate as near as possible to the wrought structure of the base metal. Finally, in the case of non-heat-treated alloys, the metal should, if possible, be annealed throughout so as to bring both the welded and unwelded portions to the same annealed condition. For the heat-treated alloys such as 13S-Q and 51S-Q, the whole of the metal after welding and hammering should be heat-treated and air or water quenched to produce a uniform condition throughout. By taking these precautions very satisfactory results have been obtained on anodising welded joints. When electric spot or seam welding is employed, very good results are produced after anodising, as in these cases only the interior of the joint is melted, the surfaces retaining their wrought structure.

Electric Arc Welding

The electric arc welding process is divided into three classes: metallic arc, carbon arc and atomic hydrogen arc welding. All these methods are being used for welding aluminium.

The metallic arc process is particularly applicable to certain classes of work, such as attaching stiffeners to large flat surfaces. There is less buckling and warping of the work with arc welding than with torch welding and preheating before welding can be largely eliminated. The temper of the sheet is less affected since the heat is much more concentrated and the weld made more quickly.

Butt welds can easily be made by this process in material .08 inch (2.032 mm.) and thicker, but lighter material is difficult to weld commercially because the high arc temperature and rapid melting of the rod make control difficult. The welding rod used is generally 5% silicon alloy heavily coated with a special flux. It is inadvisable to use arc welding if anodic oxidation is to follow.

Apparatus

The electric generator required for arc welding aluminium is practically the same as that used for similar work on other metals. It should be a variable voltage machine rated at 50 amps. or more on an open circuit voltage of about 60. For material up to ½ inch (12.7 mm.) thick a machine with a maximum capacity of 400 amps. is necessary. It is essential that the machine is of the stable arc type, otherwise a resistance of about ½ ohm must be connected in series when welding sheet ⅛ inch (3.175 mm.) or less.

The flux coated electrodes used are usually made up in lengths of about 15 inches (381 mm.) and the holders are made to clamp the end securely to ensure good contact. The correct diameter of the rod depends on the thickness of the work being welded, and varies from ⅛ inch (3.175 mm.) diameter for 14 gauge to ¼ inch (6.35 mm.) for ¾ inch (19.05 mm.) thick material.

Operation

Owing to the complete penetration produced by the metallic arc it is not necessary to prepare the edges of the sheets up to about ¼ inch (6.350 mm.) thick. For greater thickness the edges should be bevelled to form a 90° V, leaving a ⅛ inch (3.175 mm.) unbevelled lip at the base of the V.

A jig should be used to hold the work while welding proceeds. As a result of the more concentrated form of the heat, less buckling takes place than with torch welding and a less rigid type of jig is necessary. It is advisable to have a copper or iron backing strip clamped to the work, otherwise the action of the arc may blow holes and penetration will be excessive. A shallow groove should be cut in the backing plate, for if it were used flat the underside of the weld would become slightly concave on cooling, due to contraction.

When connecting up the work and electrode holder, regardless of the alloy being welded or the thickness of the work, the polarity is with the electrode positive and the work negative, or what is usually called " reversed polarity." This is primarily done to improve the arc stability.

To strike the arc, the electrode is brushed across the work, as it is found difficult to draw an arc by just touching the rod to the work; the latter method resulting in the " freezing " of the rod and work together. The electrode should be held vertical, or at any rate not more than 20° from the vertical, and worked backward and forward till a bead of the required height is built up. A short arc of ⅛ inch (3.175 mm.) to $\frac{3}{16}$ inch (4.763) mm.) in length should not be exceeded, as a long arc is difficult to maintain; moreover, a short arc helps to improve the mechanical properties of the weld by producing a rapid fusion in the work and a localisation of the heat.

A slight tendency to porosity may be somewhat reduced by using higher current values consistent with the other requirements of welding, and by preventing the metal from being chilled too quickly.

The electrode should never be worked in a side-ways motion across the weld. Moving too slowly along the seam will result in burning, as will too high a current, while moving too fast or using too low a current results in poor penetration. Practice is the only means of eliminating this trouble and operators very quickly acquire the necessary technique. As with torch welding, it is essential that all flux should be removed when the weld is completed, and a similar treatment to that recommended for finishing torch welds is desirable.

The Carbon Arc

This process can also be successfully adapted to welding certain joints in aluminium parts, but this method is not as flexible in the application as metallic arc welding. The use of the carbon arc for welding aluminium is confined at present to butt joints, either straight or corner, and to simpler types of lap joints. It is well adapted to butt joints in metal $\frac{1}{32}$ inch (.794 mm.) to $\frac{1}{16}$ inch (1.588 mm.) thick.

Atomic Hydrogen Arc Welding

This process can be used to advantage in many cases for repetition work where a good " set up " is available and where no awkward shapes or corners interfere with the free movement of the torch and filler rod.

To weld by this method a single-phase alternating current arc is struck between two tungsten electrodes and hydrogen or cracked ammonia gas is blown through the arc. Atomic hydrogen is formed by the dissociation of the molecular hydrogen and this atomic hydrogen recombines at the surface of the metal being welded, giving a very hot concentrated flame. The hydrogen completely envelops the weld, thus eliminating all possibility of the oxygen from the air combining with the molten metal. A filler rod is used as with autogenous welding, and an operator who has been accustomed to the latter process should soon become proficient when using atomic hydrogen owing to the similarity of the techniques required.

Resistance Welding

In resistance welding the welding heat is obtained by passing a heavy electric current through the pieces to to be welded, in such a manner that it flows from one piece to the other at the place where the weld is required. The heat is developed due to the current flow through the resistance of the material as well as through the contact resistance of the surfaces to be welded.

The types of resistance welding applicable to aluminium and its alloys are :—

Individual spot welding.
Continuous spot—or stitch—welding.
Roller seam welding.
Butt welding.

The equipment required is generally similar to that used for welding steel, but a very much heavier welding current is necessary, while the duration of current flow is greatly reduced.

An extremely accurate control of welding time and current, and of electrode pressure, is essential.

Spot Welding

Aluminium and its alloys have a very high thermal and electrical conductivity, consequently maximum use must be made of the contact resistance between the metal sheets being welded. A very high current is required to obtain sufficient heat from this resistance before it disappears, and the current flow has to be very brief in order to avoid undue heating of the surrounding metal.

The recent development of methods for the accurate control of welding current have made spot welding a reliable and consistent method of assembling sheets of aluminium and its alloys, particularly those which derive their strength from special heat-treatment.

Equipment

The Grid controlled Mercury Arc Valves of the Hot Cathode or Thyratron type sold by the B.T.H. Company have superseded contactors and similar mechanical methods of controlling the electrical supply to the welding transformer when short and accurate timing is required.

With these valves, the time for which the welding current flows can be controlled between one half cycle or less of the alternating current supply frequency, and several seconds.

Electrodes may be of cold rolled copper or of one of the special copper alloys that have been produced for the purpose, the choice depending on the nature of the work in hand.

Copper readily alloys with aluminium at elevated temperatures, making it essential that all possible means should be employed to prevent the electrodes from alloying

with the aluminium being welded, otherwise a surface liable to corrosion will result. If the weld be so carried out that the heated portion is concentrated at the point of contact between the two parts being welded and does not extend to the surface a great deal of the risk of alloying between the electrodes and the aluminium is eliminated. Welds carried out using a very high current over a short period of time will not only help to combat this problem, but in the case of work-hardened or heat-treated alloys, the annealing of metal surrounding the weld will be considerably reduced.

With pure copper more attention has to be paid to keeping the points of the electrode at the correct diameter, but the gain in strength of the alloys is to some extent offset by an increase in electrical resistance and consequently more rapid heating at the tip.

The shape of the electrodes is governed by the work in hand, the contour of the surface of at least one of the electrodes being generally a flat cone with an included angle of 165 to 170°. This provides a good current path and leaves sufficient metal to carry away the heat that is produced. Both electrodes are normally of this shape, but by using one electrode with a large, perfectly flat surface, it is possible to avoid any trace of a depression on one side of the work. This is of special advantage where one surface of panelling is required absolutely smooth. The electrodes should be watched carefully for signs of alloying in the copper, and can be dressed perodically, using a medium grade of emery cloth, while the tip itself can be kept clean by a touch with a fine abrasive cloth or with a glasswool stick. The size of the tip in contact with the work must be watched, and dressed up when it has a tendency to "grow." After a few thousand welds it is advisable to replace the electrodes by spares, while the first ones are trued up in a lathe.

Efficient water cooling of the electrodes is essential for production work.

The control of the electrode movement and pressure is of paramount importance. The velocity and inertia of the moving parts should be as low as possible to avoid the effect of hammer blows on the work. The use of aluminium in designing the movable electrode movement gives light weight, high conductivity as well as structural strength.

The required electrode pressure must be accurately maintained by spring or air pressure, preferably the latter, since on it depends the contact resistance between the sheets being welded.

A spot welder operated on a different principle from the Thyratron controlled machine is made by Messrs. Sciaky Electric Welding Machines Ltd. With this machine a high electrode pressure is applied to the work, giving a stress approaching the crushing strength of the material, ensuring a perfectly regular contact between the two pieces being welded. The pressure is then reduced, thus increasing the electrical resistance of the point of contact. While this reduced pressure is maintained the welding current flows, and immediately it falls in value the original electrode pressure is restored to produce a forging action which gives a wrought structure to the weld metal.

The electrical energy required for the weld is not obtained, as is the usual practice, from a single-phase transformer using alternating current. In the Sciaky machine a magnetic circuit which includes a small air gap is provided with a primary and secondary winding. A D.C. voltage is applied to the primary and a definite quantity of energy is stored in the magnetic circuit. When the primary current is interrupted a heavy current is induced in the secondary winding which is connected to the electrodes of the machine. One great advantage of this type of machine is that the load is taken from the supply over a period of time, thus avoiding the high instantaneous loads on the mains, which are often quite a serious problem with the orthodox type of spot welding.

Operation

The surface resistance of the sheets plays an important part in the production of satisfactory welds. Although surface preparation, other than the removal of dirt, is not essential with the non-heat-treated alloys or with the "Alclad" alloys, more consistent results are generally obtained by cleaning all surfaces. The heat-treated alloys require special cleaning to avoid undesirable heating and alloying of the electrodes, caused by the high-resistance surface which these alloys normally possess. This high-resistance surface can best be removed by pickling, but in many cases it is found that careful cleaning with sandpaper, or with wire brush, is equally good, and is often more practical. In general it is advisable to clean both of the inner surfaces as well as the outer surfaces.

The following Table gives values of pressure and current that can be recommended.

The pressures given are those suitable for the softer alloys, but may be increased considerably in the heat-treated alloys. In general, the highest pressure should be used which will not cause undue deformation of the sheet. The pressure control should be easily adjustable and must maintain this adjustment when once made.

Thickness of Material		Time		Welding Current	Electrode Pressure During Welding
Inches	Millimetres	*Cycles	Seconds	Amperes	Pounds
.022	0.56	1	1/50	17,000	300–500
0.36	0.91	2	1/25	21,000	400–650
.048	1.22	3	3/50	23,000	450–700
.064	1.63	4	2/25	26,000	500–800
.080	2.03	5	1/10	29,000	600–900
.128	3.25	8	4/25	36,000	700–1,200

* Based on 50 cycles per second.

It is essential that a high current flowing for a short time under exact control be used to secure the best results. No substitute, such as a longer period of flow or a lower electrode pressure, can make up for a low current value or inadequate timing, without sacrificing to a considerable extent the strength and consistency of the spots. Very satisfactory welds have however been made by using times up to 8 cycles even on thin sheet, the welding current and electrode pressure being kept high at about the values given in the Table.

For machines working on alternating current with mercury valves, it is advisable to use a small automatic induction voltage regulator, to compensate for any undue line voltage variations that may be present.

Spot welding is very suitable for joining pieces of unequal thickness, the current and pressure settings for the thinner of the sheets applying. Also, it is possible to weld, say, four thicknesses, each .036 inch (.914 mm.), with much the same setting as required for only two thicknesses, although greater current, pressure and time are required for welding two thicknesses each .064 inch (1.6256 mm.).

If spot welding is carried out correctly, the surface of the metal that has been in contact with the electrode is unchanged, and thus the resistance of the surface to corrosion is no different from that of the remainder of the metal.

Welds made in "Alclad" materials possess at least as high strength as welds made in sheet of the same alloy in the uncoated state, and while good results are obtained with the uncoated heat-treated alloys, the best and most consistent results have been obtained with the "Alclad" heat-treated alloys. The shear strength per spot, for instance, of "Alclad" 24S-T ranges from about 180 lbs. (81.646 kg.) or .016 inch. (.4064 mm.) sheet to around 600 lbs. (272.15 kg.) for .048 inch (1.2192 fmm.) sheets Not only is the strength as high, however, but the pure aluminium coating is preserved on the outside of the sheets and at the joint between the sheets, until it vanishes in the weld, and the high corrosion resistance of the "Alclad" material is therefore maintained. Spot welded "Alclad" 17S-T sheet placed in a 20% salt spray continuously for one year showed a loss of tensile strength of only 0.86%. The electrode tips also require less cleaning and have a longer life. The wide use of "Alclad" 17S-T and "Alclad" 24S-T in the aircraft industry is thus especially favourable for the adoption of spot and seam welding for aircraft work.

Spot welding machines can easily be adjusted to give a continuous succession of spot welds, the work being moved on a small distance between each welding operation. The result is a closely spaced succession of spot welds, the process being termed "stitch" welding, or continuous spot welding.

Efficiency of Spot Welding

The efficiency of a spot welded joint is the ratio of the strength of a given width of the joint to that of the same width of the continuous metal. For the figures shown below, tests were made using various strips of alloys ¾ inch (19.05 mm.) wide and .064 inch (1.63 mm.) and .036 inch (.914 mm.) thick. Two sheets were welded together with an overlap of 1 inch (25.4 mm.) and spots were made at intervals of ¾ inch

(19.05 mm.). The sheet was then accurately sheared between the welds giving specimens ¾ inch (19.05 mm.) in width, each with one spot. The average strengths shown were calculated from tests made on these specimens, and the efficiency determined by calculating the breaking load of a ¾ inch (19.05 mm.) wide strip of the same gauge and alloy.

Alloy	Gauge ins.	Gauge mm.	No. of Spots	Average Strength lbs.	Average Strength kgs.	Efficiency
17S-T	.036	.914	1	435	197	26.54%
	.064	1.63	1	670	304	22.99%
"Alclad" 17S-T	.036	.914	1	406	184	27.51%
	.064	1.63	1	710	322	27.06%
57S-¾H	.036	.914	1	510	231	59.58%

Seam Welding

There is no fundamental difference between spot and seam welding, the latter in fact may be considered as an automatic process to provide successive spot welds either overlapping or not overlapping between two or more sheets.

The electrodes consist of two rollers, one motor driven and the other an idler roll, one may be flat or slightly rounded and the other machined similar to that recommended for spot welding, the contour being a flat vee made at an angle of 7°. If desired both rollers may be of the latter type.

The pressure required is about the same as with spot welding, but the current should be slightly greater.

The power of application consists of a very short "on" period followed by a much longer "off" period, repeated successively and synchronously timed. In general, the "on" period is about 20% to 40% of the "off" period. For instance, a continuous seam weld in two sheets of .040 inch (1.016 mm.) thick 3S half-hard is obtained with a time setting of one cycle "on" and three to five cycles "off," a wheel speed giving about 15 spots per inch and an electrode pressure of about 500 lbs. (226.795 kg.). For heavier gauges, such as .064 inch (1.6256 mm.), a timing of two cycles "on," six or eight cycles "off," a wheel speed to give 10 to 11 spots per inch and an electrode pressure of 700 lbs. (317.5 kg.) may be used.

If a succession of spaced spot welds is desired the timing equipment can be adjusted accordingly. For example, with material .10 inch (2.54 mm.) thick, a speed of 10 feet (3.048 m.) per minute and an adjustment of five cycles "on" and fifteen cycles "off" will give a series of spots on ⅓ inch (8.466 mm.) centres.

Butt Welding

The butt welding of aluminium alloys, particularly when simple sections are involved, closely approaches resistance butt welding of steel.

The thermal gradient extending from the weld to the clamping electrodes is not as steep as with spot or seam welding. For this reason, precision synchronous control is not necessary except for extremely small sections. The equipment is therefore of a relatively simple nature.

An ordinary butt or flash welding machine, if of sufficient electrical capacity, will perform excellently with aluminium alloys with but few changes. Push-up is taken care of on a pressure basis rather than on a rate of travel. The time of power duration is governed by any contact device which will open the power contactor when the electrodes have travelled together a pre-set distance.

An approximate figure for pressure and current for relatively simple sections is 30,000 amperes and 2,000 lbs. per sq. inch (1.406 kg. per sq. mm.). The unsupported length of material between the welding dies will vary greatly with the section—approximately ⅛ inch (3.175 mm.) for a section of .2 sq. inch (129.032 sq. mm.) and approximately 2 inches (50.8 mm.) for a section of about 3 sq. inches (1935.48 sq. mm.). The welding time will vary from ¼ to ½ second for small sections to 5 or 10 seconds for large ones.

The electrode distance is in any event a compromise. If the section is of simple construction—without thin, mechanically weak fins or projections—the space may be made larger than in the case of complicated sections such as architectural shapes.

Current distribution, which is by far the largest problem involved, particularly with complicated sections, is improved with an increase in electrode distance. The maximum limit of this condition, however, is governed by the strength of the metal adjacent to the weld during welding. Increasing the electrode distance decreases the power required.

Spot or intermittent seam welds compare in many ways with riveted joints as to strength characteristics. This is not the case with butt welds as the entire section, of necessity, has an annealed zone near the weld and a cast zone in the weld.

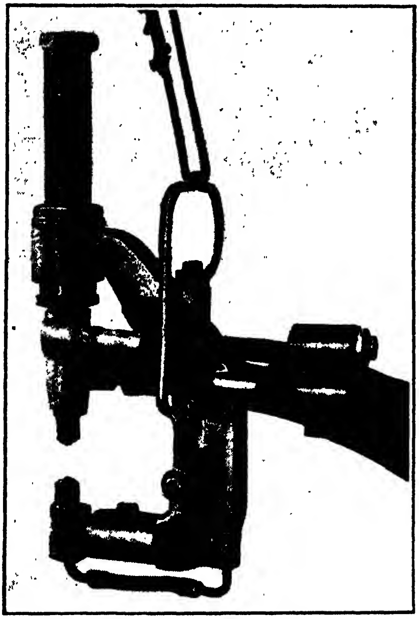


Fig. 55. *Typical Tongs for a portable spot welding machine.*

With the heat-treated alloys, however, greater strengths can be obtained by making the butt weld in annealed material and subsequently heat-treating it to the fully heat-treated condition. For example, butt weld strengths in 17S-T which range around 70-80% of the unwelded metal may be made by making the butt welds in 17S-O material and subsequently heat-treating it to 17S-T.

LIGHT ALUMINIUM ALLOYS CONTAINING NICKEL

THE metallurgist is confronted, almost daily, with the demand for better materials and one of the most important aspects of this demand is that which concerns the relation between strength and weight of structural materials. On all sides, but particularly in the fields of high-speed gyratory and reciprocating motion and of transportation, there is an almost unceasing call for materials having a high strength combined with a low weight.

Of the metals and alloys which fulfil this requirement the light aluminium alloys form a very prominent section, and it is our purpose here to discuss the properties which have enabled many of them to give service of outstanding merit.

Pure aluminium is an exceptionally ductile material but its strength is not quite sufficient for many engineering purposes. This defect has naturally led to a large amount of research, directed towards improving its strength by means of alloy additions, often associated with special heat-treatment. This increase in strength must often

be maintained at elevated temperatures and must often be combined with a fair degree of ductility and corrosion-resistance. The addition of nickel, in conjunction with other elements, has been found very efficacious in improving these physical properties and it is therefore not surprising that a wide range of modern light aluminium alloys contains this element. The variety of physical properties which can be obtained by means of variations in composition or heat-treatment gives the light aluminium alloys containing nickel a wide range of usefulness, so that they are found to-day in applications as dissimilar as domestic appliances and bridge construction.

"Y" Alloy

"Y" alloy, the first of the various light alloys containing nickel, was developed by the National Physical Laboratory to meet the need for a strong, light alloy for use in aero-engine construction, where there was an insistent demand for lighter and, at the same time, more powerful engines. "Y" alloy is an excellent all-round material; it is available in both the cast and wrought forms, with or without heat-treatment, and possesses excellent properties at elevated temperatures.

R.R. Alloys

Several years later the R.R. group of aluminium alloys was patented by Rolls Royce, Limited, as a result of a considerable amount of experimental work carried out in their laboratories. The sole manufacture of this group of alloys was taken over by Messrs. High Duty Alloys, Limited, and subsequently developed by the joint researches of their own company and that of Rolls Royce. The group consists of the now well-known alloys, R.R.50, R.R.53, R.R.56, and R.R.59, covering cast and wrought material for general purposes and for elevated temperature applications, which still remain supreme in their several spheres. Later they have been augmented by a further development, R.R.53C, this being a casting alloy which has been developed as a result of experience gained with research on the well-tried alloys R.R.50 and R.R.53, and which combines the exceptional casting properties of the former with the high tensile strength of the latter in such a way as to permit intricate parts to be cast and heat-treated without fear of excessive casting and heat-treatment stresses. It is used for parts requiring high strength and some ductility at normal temperatures, but is not recommended for use in components subjected to temperatures above 200° C., in which field R.R.53 is still considered to be superior.

The original alloy R.R.50 was developed for use for sand and die castings for general purposes, and is characterised by excellent founding properties. R.R.53, on the other hand, on account of the high degree to which it retains its strength and hardness at elevated temperatures, has been developed principally for use in die-cast pistons and cylinder heads.

R.R.56 is the wrought variety, and is now obtainable in a large variety of forms such as bars, tubes, sections, sheets, forgings and drop stampings. R.R.59 is the wrought variety of R.R.53, and is used mainly for pistons and cylinder heads.

"Ceralumin"

Mention should also be made of a somewhat similar type of alloy which has been placed on the market by Messrs. J. Stone and Company, Limited, Deptford, under the name of "Ceralumin."

"Lo-Ex"

The light weight of aluminium alloys, combined with their high value for thermal conductivity, has given them definite advantages over cast iron for automobile and other pistons. Since, however, most aluminium alloys have a coefficient of linear expansion of the order of 23 millionths per °C., as compared with 10 millionths per °C. for cast iron, attempts have been made to overcome the differential expansion between the aluminium alloy piston and the cast-iron cylinder or cylinder liner. For example, recourse has been had to the "split skirt" and "Invar strut" types of piston which overcome to a very large extent the slap which occurs with light alloy pistons when the engine is running cold. In the aluminium alloy known as "Lo-Ex" advantage is taken of the fact that silicon in sufficient quantity considerably reduces expansion, and by the addition of nickel increased hardness and improved properties at elevated temperatures are obtained. In connection with this alloy, reference may be made to the fact that the corrosion-resisting austenitic nickel cast iron "Ni-Resist" has a similar coefficient of expansion to that of "Lo-Ex," and consequently opens up interesting possibilities in engine design.

COMPOSITION, CHARACTERISTICS AND PRINCIPAL PROPERTIES OF A RANGE OF ALUMINIUM ALLOYS

MATERIAL	BSI OR DTD SPEC	Form	COMPOSITION Si.	Mg.	Mn.	Ti.	Fe.	0.1% Proof Stress: Tns/In²	Ult. Stress: Tns/In²	Elong: % on 2 In.	Brinell.	Fatigue Tns/In² ±	Type	CHARACTERISTICS AND APPLICATIONS.
HIGH CORROSION RESISTING ALLOYS.														
Hiduminium Anticorodal 15.	DTD.213.	W			1.25	.2	"	3-14	6.5-16	40-3	27-60	3.6-5	WH	Corrosion resistance equal to, or better than pure Al. Supplied mainly as sheet in three tempers according to degree of work hardening. Plant for chemical and food industries and cooking utensils.
Hiduminium Anticorodal 23. Hiduminium Anticorodal 33. Hiduminium Anticorodal 35.	- BSI.L46. -	C W W		3 3 5	1.3 1.3 1	N .2 N .2 N .2		4-7 6-23 9-27	9-11 15-26 20-30	7-3 25-3 25-2	40-70 40-110 45-120	4.8-6.9 8.25 8.25	- WH WH	Excellent corrosion resistance and good strength. Used extensively for chemical plant, architectural and marine work. Good welding and forming properties. Sand and die castings and all wrought forms.
Hiduminium Anticorodal 40. Hiduminium Anticorodal 42. Hiduminium Anticorodal 45.	- - DTD423A.	C C W	2.3 5 1	.7 .7 .75	.7 .7 .75	.15 .15 -		6-18 4-19	8-19 7-23	4-1 27-10	60-100 30-120	4-5 9-9.5	HT HT	As above but require heat treatment which affords much higher strength in cast form and better combinations of properties in wrought forms. "42" possessing higher Si content has better fluidity for more intricate castings.
Hiduminium Anticorodal S.10	BSI.L33.	C	11.5	-	-	-		3.5-4.5	10.5-14	15-5	45-65	-	-	Excellent fluidity and freedom from hot shortness for intricate or thin sectional castings. Corrosion resistance and applications as above, specially suitable for fermentation plant in which Mn has detrimental effect.
Alpax Beta. Alpax Gamma.	DTD.240. DTD.245.	C C	12 12	N.6 N.6	N.6 N.6	- -	N.6 N.6	6-9 13-16	11-17 15.5-20	2-4 3-0	75-85 95-100	- -	HT HT	Addition of Mn & Mg to above alloy gives it an Al-Si-Mg-Mn constitution amenable to heat treatment whilst retaining the excellent casting and other characteristics associated with a high Si content. Beta and Gamma have same composition but different heat treatments giving higher values for the latter. Used in general engineering, and applications similar to those mentioned above.

MATERIAL	BSI OR DTD SPEC	Form	Cu.	Si.	Mg.	Ni.	Fe.	Ti.	Mn. / Other Elements.	0.1% Proof Stress: Tns/In²	Ult. Stress: Tns/In²	Elong: % on 2 In.	Brinell.	Fatigue Tns/In² ±	Type	CHARACTERISTICS AND APPLICATIONS.
HIGH STRENGTH COPPERBEARING ALLOYS FOR GENERAL ENGINEERING & STRUCTURAL WORKS.																
Duralumin.	BSI.6L1.5L3 4T4.2L38.39 395.396.477 532. DTD.147.150	W	4	N.7	.5		N.7	.3	.5	15-17	25-28	15-20	100-120	9.3	HT	A high strength natural ageing alloy established and widely used in general engineering for many years. Strength not as great as in more recent developments, such as Hiduminium R.R. 56, which now replaces it largely in aero-engines, but it is still extensively used for its particular combination of mechanical properties and natural ageing characteristics.
Alloy.	BSI.2L24.435 703.704	C	4	N.6	1.5	2	N.6	.08	Si +N1 Fe	13-16	14-20	2-3	100-130	5.8-7.1	HT	Alloys for pistons, cylinder heads and applications subject to elevated temps. They are still widely used although they have now been replaced to a considerable extent by the more recent Hiduminium R.R.53 and 59.
Y Alloy.	BSI.4L25.414 478.533	W	"	"	"	"	"	"	"	14-17	24-27	15-20	100-130	9.3	HT	
Hiduminium R.R.50.	DTD.133B	C	1.3	2.2	.1	1.3	1	.2		9-13	11-16	2-6	65-80	4.5-5.8	HT	Excellent combination of properties for general purpose sand and die castings, especially in automobile and aircraft engineering, such as cylinder blocks, engine casings, brake drums, axle casings etc.. It is subjected only to a low temp. precipitation treatment which obviates the possibilities of distortion, high internal stress and cracks in massive castings. Actual mech. props. afford little indication of the all round excellence of this material for general foundry work.
Hiduminium R.R.53C.	DTD.313.309	C	1.4	2.5	.6	1.0	1.1	N.3		9-21	14-24	1-3	70-121	7.2-8.4	HT	Higher strength casting alloy for stressed machine and structural components. Subjected both to Soln. & precipitation treatments. More difficult to cast than "50" and owing to high temp. heat treatment it should be used only for castings of relatively simple design such as levers, brackets etc.
Hiduminium R.R.56.	BSI.2L40.L45 L47. DTD.130A.206 179.22A.410 184.246A.	W	2.0	.7	.8	1.3	1.2	.1		7-23	16-30	10-25	45-138	8.8-10	HT	Standard high strength general purpose wrought alloy for forgings, stampings, pressings, extrusions, sheet and strip, wire etc.. One of the most widely used materials in general and aero-engine engineering, and is particularly suitable for all types of wrought highly stressed components in internal combustion engines. Excellent hot working properties and homogeneity. Size of products limited only by capacity of plant.
Hiduminium R.R.77.	DTD.363.	W	2.3	N.6	3.0	-	N.6	N.3	Mn N1 Zn5	4-33	12-38	10-20	45-180	12.5-13	HT	The highest strength light alloy yet developed. Specific strength exceeds that of high tensile steel alloys. Possesses also excellent combination of other mechanical and physical properties. Hot working is rather more difficult than in "56". Alloy is used for highly stressed structural purposes and is obtainable in all wrought forms.
Hiduminium R.R.53. Hiduminium R.R.59.	DTD.238.131A BSI.2L42	C W	2.3 2.3	1.8 -	1.6 1.6	1.3 1.3	1.2 1.2	.1 .1		19-22 18-22	18-23 35-30	.5-1.5 6-15	124-148 124-130	5.5-6.9 10.3	HT HT	Wrought and casting alloys used extensively for pistons, cylinder heads and other applications subject to stress at elevated temps. At 20°C, 200°C, 250°C and 300°C U.T.S. of "59" & "53" (d/cst) are respectively 28, 21.5, 19.5, 13.0 and 24, 22, 19.5, 15.5 tons per sq. in.
Hiduminium 72.	DTD.270.273 275.280.290	W	4.2	N.5	1.3	-	N.4	-	Mn.9	18-24	23-31	15-20	129-148	11.5	HT	A natural ageing alloy for extrusions, sheet & strip, affording somewhat better mechanical properties than dural.

NOTES. Form:- W = Wrought. C = Cast. Type:- WH = Work Hardening. HT = Heat Treatable. Composition values are percentages. N = not more than.
The values given under Mechanical Properties vary between the limits shown, according to method of heat treatment, degree of work hardening or method of casting.

Table XII.
Chemical Compositions.

Alloy.	Cu	Ni	Mg	Fe	Si	Mn	Ti
"Y" ..	4.0	2.0	1.5	0.6*	0.6*	—	—
R.R.50 ..	1.3	1.1	0.12	1.1	2.30	—	0.18
R.R.53 ..	2.1	1.3	1.5	1.1	1.0	—	0.07
R.R.53C ..	1.2	1.3	0.5	1.1	2.5	—	0.16
R.R.56 ..	2.0	1.3	0.8	1.2	0.6	—	0.07
R.R.59 ..	2.2	1.3	1.5	1.2	0.85	—	0.07
Ceralumin "C"	2.5	1.5	0.8	1.2	1.2	—	Ce 0.15
"Lo-Ex" ..	0.9	2.0	1.0	—	14.0	—	—
"Birmasil Special"	0.1*	2.5—3.5	—	0.6*	10.0—13.0	0.5*	—
"P.2" ..	3.0—4.5	1.75—2.5	0.5*	2.0—4.0	4.0—5.0	0.5*	—

* Maximum.

N.B.—Attention is drawn to the fact that certain of the above alloys are covered by patents.

Table XIII.
Mechanical Properties of Wrought Alloys.

Alloy	Heat Treatment.	Tensile. Proof Stress 0.1%. t.s.i.	Tensile. Yield Point t.s.i.	Tensile. Maximum Stress. t.s.i.	Elongation %	Brinell Hardness Number.	Limit.
"Y"	Complete	—	15—18	23—27	18—24	100—110	±10.2**
R.R.56	Annealed	6—8	—	12—16	20—25	55—65	—
,,	Normalised annealed	8—10	—	16—19	18—22	70—80	±9.3*
,,	"Solution" only	10—13	—	22—26	15—20	80—100	± 9.3*
,,	Complete	21—23	—	27—32	10—15	125—148	±10.3*
R.R.59	Complete	20—22	—	26—28	10—15	125—148	±10.3*

* 40,000 reversals. ** 10,000,000 reversals.

Table XIV.
Mechanical Properties of Cast Alloys.

Alloy.	Form.	Heat Treatment.	Tensile. Proof Stress 0.1%. t.s.i.	Tensile. Yield Point. t.s.i.	Tensile. Maximum Stress. t.s.i.	Elongation. %	Brinell Hardness.	Fatigue Limit. t.s.i.
"Y"	Sand Cast	Quenched and Aged	—	—	14—16	1—3	95—105	—
,, ..	Chill Cast	,, ,,	—	—	18—20	3—5	100—110	±7.1*
R.R.50 ..	Sand Cast	Precipitation only	9—11	—	11—13	2—4	65—75	±4.5**
R.R.53	Die Cast	,, ,,	11—13	—	13—16	4—6	70—80	±5.8**
,, ..	Sand Cast	Complete			18—20	0·5—1·0	124—148	±6.9**
,, ..	Die Cast	,, ,,	19—22	—	21—23	0.5—1.5	124—148	—
R.R.53C ..	Sand Cast	"Solution only	9—10	—	14—15	2.5—3.0	70—75	—
,, ..	,, ,,	Complete	18—20	—	19—22	1—2	100—115	—
,, ..	Die Cast	"Solution" only	10—12	--	18—20	6—8	75—85	—
,, ..	,, ,,	Complete	19—21	—	22—24	3—6	110—120	—
Ceralumin "C"	Sand Cast	"Solution"	11—13	—	14—16	1—3	98—104	—
,, ,, ..	,, ,,	Complete	18—20	—	19—20	0—1	130—140	—
,, ,, ..	Chill Cast	"Solution"	13—14	—	19—21	4—6	98—104	—
,, ,, ..	,, ,,	Complete	21—24	—	23—27	0—1	130—140	±8.25*
"Birmasil Special" ..	Sand Cast	—	—	7—9	12—14	2—4	50—70	±3.5*
,, ,, ..	Chill Cast	—	—	8.5—10.5	16—18	3—86	70—8	Œ5.3*
"Lo-Ex" ..	,, ,,	—	—	9.5—11.5	10—13	0—0.5	65—75	—
,, ..	,, ,,	Complete	—	15.2.-16.4	16—19	0—0.5	125—140	—
"P.2" ..	Pressure Die Cast	—	—	7.0—11.5	9.5—12.25	0.5—2.0	65—101	±4.25*

* 20,000,000 reversals. ** 40,000,000 reversals.

Table XV.

Physical Properties.

Alloy.	Specific Gravity.	Thermal Conductivity c.g.s. units.	Coefficient of Linear Expansion per °C. from 20–100 °C.	Pattern Makers' Shrinkage, inch per foot.
" Y "	2.80 (Max.)	0.42	0.000022	0.155
R.R.50	2.73	0.415	0.000022	0.125
R.R.53	2.73	0.43	0.0000224	0.140
R.R.53C	2.73	0.415	0.000022	—
R.R.56	2.75	0.426	0.000022	—
R.R.59	2.75	0.428	0.000022	—
" Lo-Ex "	2.65-2.75	0.28-3.4	0.000019	0.048 0.084
" Birmasil Special "	2.65-2.75		0.000019	0.156
" P.2 "	2.7-2.9			

" Birmasil Special "

The plain high-silicon type of aluminium alloy is characterised by good founding properties coupled with excellent resistance to corrosion, but suffers from the drawback that it possesses rather a low value for the yield point. Taking this material as a basis, Messrs. The Birmingham Aluminium Casting (1903) Company, Limited, have patented and developed an alloy known as " Birmasil Special." By adding up to 3½ per cent. of nickel they have produced an alloy having high tensile strength in the as-cast condition, coupled with excellent corrosion-resistance, ductility and toughness.

" P.2 " Alloy

The importance of being able to produce castings to close tolerances, in order to avoid undue machining, lends interest to the " P.2 " light aluminium alloy developed by the above firm for pressure die castings. By the use of this alloy it is possible to produce regularly quite complicated castings up to a maximum of 8 lb. in weight with a tolerance of ±0.0025 inch of diameter or length. The minimum limit for wall thickness for small castings is 0.06 inch, and for holes 0.09 inch width or diameter.

Table XVI.

Heat Treatment.

Alloy.	Anneal. °C.	Anneal. Hrs.	Solution Treatment. Heat at °C.	Solution Treatment. Hrs.	Solution Treatment. Quench in.	Ageing Treatment. Heat at °C.	Ageing Treatment. Hrs.	Ageing Treatment. Quench in.
Cast Alloys								
"Y" ..	—		510—520	2	Boiling water	100	2—3	Water or air
" ..	—		510—520	2	" "	Room temperature	120	
R.R.50 ..	—		—	—	—	170	10—20	" "
R.R.53 ..	—		525—535	2—4	Boiling water	170	15—20	" "
R.R.53C ..	—		525—535	2—6	" "	165	15—20	" "
Ceralumin "C"	—		515—535	4—6	Water	175	16	Water
	—							
"Lo-Ex" ..	—		515	2—3	"	180	2	—
Wrought Alloys	—							
"Y" ..	360	¼—4	510—520	2	Boiling water	100	2—3	Water or air
" ..	—		510—520	2	" "	Room temperature	120	
R.R.56 ..	360	¼—4	525—535	2	Water at 70°C.	170	15—20	" "
R.R.59 ..	360	¼—4	525—535	2	" "	170	15—20	" "

N.B.—In the case of intricate castings and forgings it is advisable to commence heating the component for the solution treatment with the furnace at 300-350 °C.

Properties of Nickel-Aluminium Alloys

The chemical composition and general mechanical properties of the above-mentioned aluminium alloys are given in Tables XII-XV, which show the high tensile strength which it is now possible to obtain, not only in wrought but in cast material. The heat-treatment necessary in order to obtain these high values is indicated in a concise form in Table XVI. It is outside the scope of this publication to go deeply into the question of the heat-treatment of aluminium alloys, but it may be stated that in order to obtain the full mechanical properties the usual procedure consists of a " solution " treatment followed by a " precipitation " or " ageing " treatment. The former consists of heating to a high temperature followed by rapid cooling, and results in retaining the various hardening constituents in solid solution. After this " solution " treatment the aluminium alloy is, however, only slightly harder than in the annealed state, and it is not until the " ageing " treatment has taken place that full hardness is developed. The " ageing " treatment may occur at room temperature (natural " ageing ") or at elevated temperatures, 100°–200° C. (artificial " ageing ") and is the result of the precipitation of ultramicroscopical particles from the solid solution. It will thus be seen that the mechanism of the heat-treatment of aluminium alloys is rather the reverse of that of steel.

Certain alloys, such as " Y," commence to " age " naturally at room temperatures immediately after the solution treatment, but the R.R. alloys will not do so and must be subjected to a temperature of about 170° C. before precipitation hardening occurs. Advantage can be taken of this fact, especially in the case of cold shaping, since the material can be supplied in the " solution " treated condition, and then after the necessary fabrication the user need only carry out the low-temperature treatment in order to develop the full properties.

Aircraft and Automobile Engineering Applications

The light weight and the relatively high tensile strength, which are associated with aluminium alloys, have naturally led to their extensive use in the aircraft and automobile industries. One of the earliest uses, as has been mentioned previously, was in connection with pistons for aero-engines, and much experimental work had been carried out since, with the result that at the present time the most suitable alloys for this purpose are " Y " alloy, R.R.53, Ceralumin C, and " Lo-Ex " for cast pistons, and " Y " alloy and R.R.59 for forged pistons. By using such alloys in place of cast iron, it is possible to reduce the weight and stresses on the bearings, and also to lower the piston and bearing temperatures, thus allowing much higher piston speeds to be obtained. In piston design it is necessary to arrange for the heat absorbed by the piston crown to be conducted away as rapidly and evenly as possible in order to avoid distortion due to unequal expansion. The thermal conductivity of " Y " alloy and the R.R. alloys, as will be seen from Table XV, is about three times that of cast iron, and considered in conjunction with the fact that the density is one-third, the advantages are obvious.

Modern practice in the aircraft industry is to use forged pistons of either " Y " or R.R.59 alloy, especially in the case of the higher powered engines, but in the automobile industry the tendency is towards the use of gravity die castings. Incidentally, since " Y " and R.R. alloys possess excellent wear resistance, it is possible to run the hardened steel gudgeon pins direct on to the metal without the use of phosphor bronze or other bushes. As has been mentioned previously, " Lo-Ex," because of its relatively low coefficient of linear expansion, is extensively used in the motor-car industry for pistons.

Forged " Y " or R.R.56 is also used for connecting rods since it enables the weight of reciprocating parts to be reduced with a consequent lowering of the load of the bearings. The R.R.56 alloy is used in the De Havilland and other aero-engines, as well as in petrol and compression ignition automobile engines.

The reasons which favour the use of aluminium alloys for pistons are applicable in the same degree to cylinder heads, especially of air-cooled aero-engines. Similar alloys are used for pistons, and in recent years there has been a tendency to change from cast to forged heads. In this connection the " Bristol " cylinder head is of particular interest in that it was the first aluminium alloy forging to be used for this purpose. In the automobile industry cast iron is still largely employed, but for special engines in which a high power output is required, cast aluminium alloys such as " Y," R.R.50, R.R.53, and " Birmasil Special " are used.

Whilst wood has given excellent service for aircraft propellers, it has a tendency under certain climatic conditions to warp and does not always resist very satisfactorily

Mechanical Properties.

Position of Test Piece.	Ult. stress tons/sq. in.	Elongation % on 2 inch.	Brinell Hardness Number.
1	27.0	10.0	134
2	27.0	10.0	129
3	26.9	12.5	134
4	27.3	15.0	129
5	27.2	12.0	129
6	27.1	12.5	134

the eroding action of heavy rain and hail storms. Consequently there has been a decided increase in the use of metal propellers, R.R.56 being the alloy generally used.

The development of aero-engine crank cases is exceedingly interesting, especially in view of the fact that it has enabled the drop forger to reveal his art in producing stampings both intricate in shape and large in size, a proceeding which would have been considered to be impossible not many years ago. The R.R.56 crankcases may be used in the fully heat-treated condition, but in those cases where the design is of necessity very intricate, in order to save weight it may be necessary to use the crankcases in the annealed condition, thus avoiding the slight distortion which might appear if the full heat-treatment were to be given.

For those crankcases and similar components where, owing to the design, it is impossible to use a forging, R.R.50 is widely used. Examples include the Rolls Royce, "Kestrel" and "Merlin," and the Napier Halford aero-engines.

Other applications in this field for castings are :—commercial vehicle and motor-car wheels, brake shoes, blower casings. Extruded sections and tubes are being extensively used for aircraft construction, motor bus frames and seats, and forgings for impellers and various aircraft brackets and fittings.

WROUGHT MAGNESIUM ALLOYS

By F. A. FOX, M.Sc.,

Chief Metallurgist, Magnesium Elektron, Ltd.

In this country, magnesium alloys used in the wrought state are : an alloy containing 6% aluminium, 1% zinc and 0.2% manganese for extrusion, one containing about 8% aluminium, 0.4% zinc and 0.2% manganese for forging, while an alloy used for rolling consists of the binary magnesium-manganese alloy containing about 1.5% manganese.

Sheet

An interesting development of the past two years in this country has been the rolling of the manganese-containing sheet alloy directly from cast slab. It was thought for many years that no magnesium alloy could be satisfactorily rolled without the initial stage of extrusion. The practice used to consist of extruding a billet about 12 inches in diameter into the form of a "blank" about 1¼ inches thick. This was then hot rolled with various reheatings to a thickness near the finished gauge, the last few thousandths of an inch reduction in thickness being made cold. By producing a slab under carefully controlled casting conditions, the manganese alloy can now be rolled direct, and the mechanical properties of the finished sheet are as good as those of the same alloy which has been extruded as well as rolled.

In the U.S.A. a sheet alloy containing about 3% aluminium and 1% zinc is used, and also one containing about 4% aluminium. These give sheet with quite good mechanical properties, but they are not so easily rolled as is the single-phase magnesium-manganese alloy, and the production rate is much reduced. They are also much more difficult to weld.

An interesting point about the magnesium-manganese and other magnesium base alloy sheet is that any directionality which occurs is not in the usual sense. All the properties are higher in a direction at right angles to the principal rolling direction than in the longitudinal direction. Where the rolling reductions are correctly applied,

and reheats properly spaced, the actual amount of this directionality is small. In improperly reduced sheet the directionality can be large, the following being an example of the difference between the two directions :—

Mg.-Mn. Alloy Sheet	0.1% Proof Stress Tons/ins.	Ultimate Tensile Stress Tons/ins.	% Elongation on 2″
Longitudinal ..	6	13	5
Transverse ..	9	16	10

This directionality is connected with the crystal orientation of the sheet. Both hot and cold rolling produces an orientation of the crystals with the basal plane (0001) parallel to the plane of the sheet. This orientation is never perfect, and it has been found that there is a certain amount of scatter of the basal planes which appears to be greater in the longitudinal than in the transverse direction. Since, in a single crystal, the proof stress is large when the (0001) plane is parallel to the stress, it is relatively easy to argue from this difference in the departure from perfect orientation that the proof stress of the sheet in the transverse direction should be—as it actually is—greater than that in the longitudinal direction. It is, however, less simple to explain the differences in the other mechanical properties on this basis. An interesting recent paper by Bakarian deals with the orientation of magnesium alloy sheet.

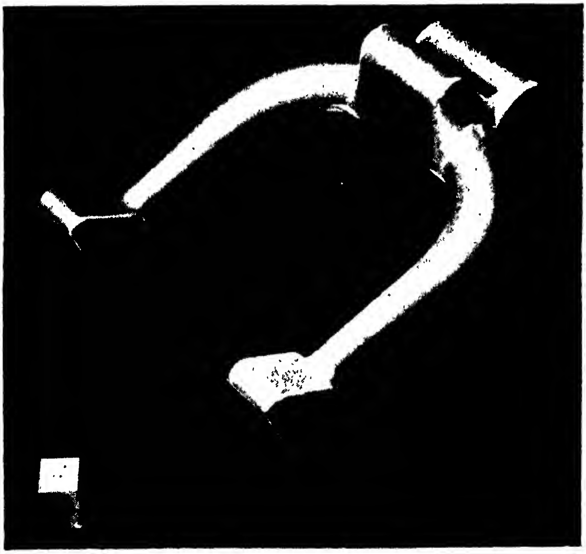


Fig. 56.—Tailwheel Fork Stamping in Hiduminium R.R.56. Weight 8¼ lbs., overall length approximately 14 inches. The preparation of the dummy for this part presents some difficulty in that it is necessary to use a bolster tool for the shank end as well as bending tools for the arms. The micrographic specimen introduced on the left of the picture for size comparison has a top surface of exactly 1 inch square. This is the fork of the "Spitfire."

This magnesium-manganese sheet welds very satisfactorily with the oxy-acetylene torch, and ultimate tensile strengths of well over the A.I.D. requirement of 8 tons/in. can be obtained across an unhammered weld.

It is essential to use a suitable flux for the welding of magnesium alloy sheet and tube, and this usually contains some constituent which acts as a solvent for magnesium oxide. It is also desirable to avoid the use of a flux containing sodium salts, since these tend to cause obscuration of the work by their intense colouration of the flame.

The manganese-containing sheet will successfully withstand simple forming operations at room temperature, while severe forming or drawing is applied at a temperature about 350° C. At this temperature directionality effects are not importantt, the sheet is readily workable, having great ductility in a wide plastic range, and the ultimate tensile stress of the sheet is now about 2.5 tons/in. The temperature for hot working the sheet is not critical so long as it is reasonably well above the temperature of about 225° C., and as long as the temperature is not so excessive as to cause rapid grain growth. The temperature of 225° C. is that at which in pure magnesium a new set of slip planes becomes operative, and greater ductility is conferred on the material. This temperature is probably approximately correct also for the magnesium-manganese alloy. Grain growth does not occur until temperatures much in excess of 400° C. are reached. The tendency to grain growth following "critical" cold work, although present in pure magnesium sheet, is much reduced by the presence of the manganese in the alloy.

The bending radius which can safely be put on this sheet alloy is approximately 5T.

Extrusions

A large amount of tube is extruded in the 6% aluminium, 1% zinc, 0.2% manganese alloy (Elektron AZM), and this is used, *inter alia*, for the fabrication by welding of seats in aircraft. In addition, extruded rod and section are used for the manufacture of various aircraft components and as "stock" for forging.

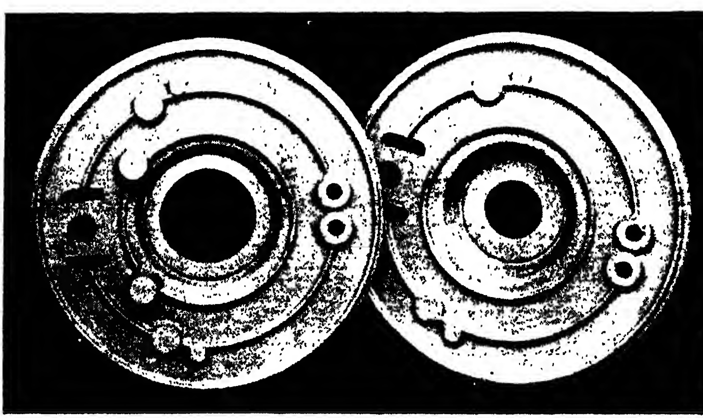


Fig. 57.—Sandcastings on "Hiduminium R.R.50. Brake Drums.

This alloy is most satisfactory for general purposes as far as the extrusion process is concerned, since it has a moderate aluminium content (the higher the aluminium content the slower is the extrusion speed), while the presence of 1% zinc has a slightly beneficial effect in assisting corrosion resistance. Extrusions in this alloy are not quite so strong as those with a higher aluminium content, but the advantage of greater extrusion speed, which is possible because of the lower aluminium content, more than counterbalances the disadvantage of the slightly lower strength.

Recent Russian work has shown that the extrusion alloy Elektron AZM undergoes a sudden increase in plasticity at the temperature of 360° C.[1]

[1] Gubkin and Savitsky, *Compt. rend.* (*Doklady*) *Acad. Sci. de l'U.R.S.S., Nouvelle S'rie*, 1940, 28, (2), 131.

Forgings

Although a considerable number of forged components is made from extruded Elektron AZM, a number of quite large forgings is produced in the alloy containing 8% aluminium, 0.4% zinc, 0.2% manganese; this is the alloy Elektron A8. Although this alloy will not extrude rapidly, it is sufficiently workable at temperatures between 350 and 400° C. to be readily die forged or pressed, and it is also capable of being hot swaged. The forging pressures required for small components are lower than those for corresponding parts in aluminium alloy. High pressures are required for forging large components, since it is important to ensure that the work shall penetrate the whole piece and shall not be confined to the surface layers.

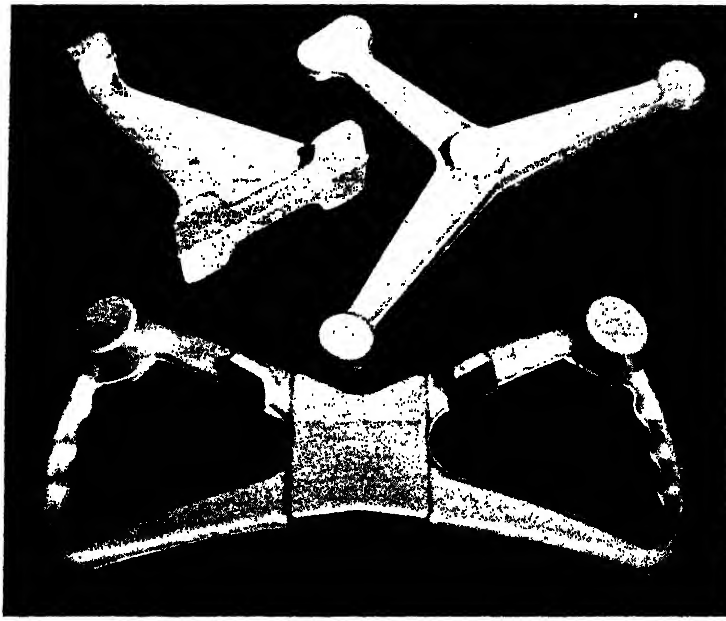


Fig. 58.—Stampings in Hiduminium R.R.56:—Top Left: Elevator Bracket. Weight 1 lb. 2 oz. H-shaped base 5½ inches long × 2½ inches wide at ends and 1½ inches wide in centre. Overall height 8¼ inches × ¼ inch fillets. This is an example of a stamping where radii at the juncture of the plate and ribs, and also correct moulding to induce metal distribution without undue waste, are important factors. Top Right: Control Lever. Weight 1 lb. 2 oz.; pit circle of boss ends is 12 inches diameter; central boss 1¾ inches × diameter × 1⅝ inches thick, holed out in centre for boring location. In order to obtain the desired grain flow, extreme care is required in the formation of this stamping. Generous radii are provided on all corners to facilitate production and eliminate undue weakening of the dye. In sections of this nature the fillet at the H-section juncture should be ¼-inch radius minimum to avoid any tendency towards shear lines appearing at these positions during the stamping. Below: Control Wheel. Weight 2¾ lbs., overall length 15 inches; width at ends 6¼ inches; 3/16-inch fillets. This stamping illustrates a type which requires moulding in order to obtain the correct distribution of metal to the various cross-sections without undue waste. Distortion is likely to occur during heat treatment, necessitating a setting operation immediately after solution treatment.

The mechanical properties of forgings with even higher aluminium contents than 8% would be slightly better from the point of view of proof stress and ultimate tensile

stress, but would be distinctly inferior from the point of view of percentage elongation. For this reason more highly alloyed materials are not used in forging.

Although for the greatest uniformity of properties and for the highest test figures it may be desirable to forge extruded blanks, it is nevertheless readily possible, and in some cases even preferable, to forge cast blocks in this 8% aluminium alloy. The forging must be carried out relatively slowly, hydraulic pressure being the most satisfactory. The piece is also usually turned through 90° in successive operations, in order to ensure reasonably uniform distribution of the hot work and to avoid the production of excessive directionality. Forged components can be made in this alloy to resist large hydraulic pressures; for example, a hydraulic cylinder is now being made, the finished wall thickness of which is only $\frac{3}{16}$ inch, and the internal test pressure is 4,000 lb./in.

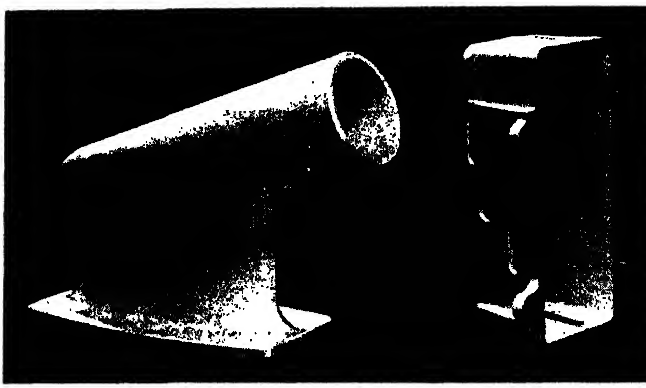


Fig. 59.—Left: Aileron mass balance arm. Right: Front cover for inner starboard control sprocket box. Both cast in "Magnuminium" magnesium-base alloy.

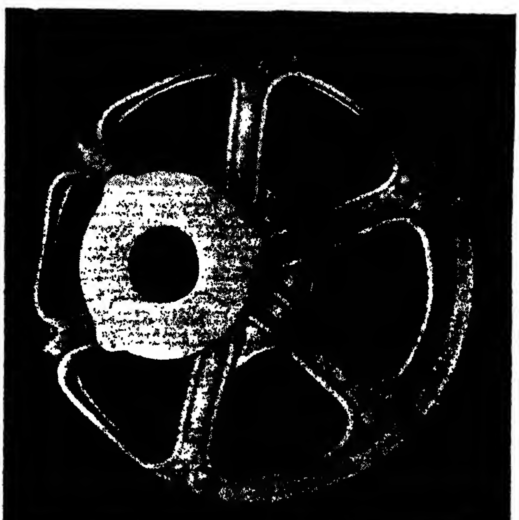


Fig. 60.—Photograph shows one side of an aeroplane wheel cast in "Magnuminium" magnesium-base alloy. The complete wheel is made up by bolting two such castings together. Magnesium-base alloy aeroplane wheels are also cast integrally in one piece.

Surface Protection

A very great number of patents has been taken out to cover different protection treatments for magnesium alloys. Some of these are quite impracticable commercially; some of them involve expensive solutions, such as tungstates and molybdates, and others require complex electrolytic treatments.

Many attempts have been made to anodise magnesium alloys, but unfortunately the films produced have so far fallen far short of the aluminium-oxide layer produced by anodising on aluminium alloys, both in respect of continuity and hardness.

The protection methods which have been most successful have been those of the type of a simple chemical dip, whether in cold or boiling solutions.

An essential characteristic of any general-purpose protective layer applied directly to the alloy is that it should act as a suitable basis for paint. The protection of magnesium alloys should be regarded as a combination of the chemically produced layer and the paint, and magnesium parts are always used protected in this way.

The successful protection of magnesium alloys by paint is connected with the choice of a satisfactory primer. Zinc chromate is frequently used as a pigment in the primer, and this compound has the effect of assisting in reducing corrosion. Iron-containing pigments are to be avoided, as it has been found that these accelerate corrosion.

Fig. 61.—Main brake casting in "Magnuminium" magnesium-base alloy.

The primers are usually synthetic resin based, and over the primer coat enamels or nitrate cellulose lacquers may be applied.

Many attempts have been made to plate magnesium alloys, but so far these have been conspicuously unsuccessful. The difficulty has been to obtain firstly a metallic coat which will be closely adherent to the metal and, secondly, to produce a sufficiently non-porous plating. If the plating is porous to any great extent, or should a scratch penetrate the plate, severe galvanic action is likely to set in between the metal of the plate and the magnesium, by which the magnesium would be rapidly attacked. The table gives an indication of the corrosion rates of magnesium in electrolytic contact with other metals.

The Relative Corrosion Rate of Magnesium Coupled to Other Metals.

Second Metal of Couple.	Pt.	Al.	Fe.	Ni.	Cu.	Pb.	Mn.	Zu.	Mg. alone
Relative corrosion rate of magnesium ..	19.4	15.9	9.85	7.70	5.46	4.31	2.70	1.62	Arbitrary standard 1.

It will be seen that aluminium in particular, when coupled with magnesium, causes violent attack to be concentrated on the magnesium. For this reason it is essential in constructing assemblies of magnesium and aluminium alloys that the two metals should be well insulated from each other. It has been found that the aluminium base alloy MG5 or MG7 producês a much smaller harmful effect on magnesium than does Duralumin. Stainless steels and cadmium-plated, plain carbon-steel in electrolytic contact with magnesium do not cause very serious corrosion, although it is in practice again necessary to ensure proper insulation.

Attempts have been made to "clad" magnesium sheet with some more corrosion-resistant material. "Cladding" with aluminium is obviously unsatisfactory, because of the severe effect of the attack which would develop at cut edges and in the event of accidental puncturing of the aluminium surface. A small amount of sheet has in the past been experimentally produced, consisting of the strong alloy Elektron AZM, which contains 6% aluminium and 1% zinc, which was "clad" with the more corrosion-resistant alloy Elektron AM503. This protection method, however, was never put into commercial practice, since magnesium alloy sheet, being used in any case in thin section, could carry only a small thickness of protective plate, and it was considered that the risk of penetration of the "clad" surface was again great. In addition, the "cladding" process in itself offered considerable difficulties.

The mechanical properties of the alloy Elektron AM503 have been improved by improvements in rolling technique, and this is the sheet alloy which is now the most widely used, and which is most corrosion resistant; this renders the use of "clad" sheet unnecessary.

In practice, the avoidance of corrosion of magnesium alloy parts is not a difficult or tedious matter. The corrosion of magnesium alloys, even when exposed unprotectep to atmospheric attack, is much slower than for mild steel, which also requires protecting in a similar way.

Magnesium alloys are also free from that bugbear of other non-ferrous materials, such as aluminium, zinc, and copper base alloys—intercrystalline corrosion. No stress corrosion effects have been observed for magnesium alloys.

Deep Drawing

In recent years considerable progress has been made in the direction of drawing magnesium alloy sheet. Hydraulic presses are used, and the stroke speed varies between about 10 and 20 ft./min. The lower die and pressure pad are heated so that the drawing operation can be carried out at the appropriate working temperature of about 350° C. The dies are designed to give high percentage reductions, and the lower die has a minimum entering radius of five times the sheet thickness, although it is preferable for the radius to be considerably greater than this figure.

The sliding surfaces of the draw ring and pressure pad are polished and lubricated with a 20% mixture of graphite in tallow. The lowest possible pressure consistent with the prevention of wrinkling is applied to the blank holder, in order to minimise the danger of tearing of the sheet. If tolerances closer than $\pm$ 0.1% of the diameter are required, the hot drawing operation may be followed by a cold sizing operation which will reduce the tolerances to $\pm$ 0.04% of the diameter. With such technique cylindrical cups of depths up to $1\frac{1}{2}$ times the diameter, and square shells with depths equal to the side dimensions, are easily made, reductions of more than 60% being accomplished in a single draw.

For shallow draws, electrically heated steel lower dies are used with a rubber-forming element. Under these conditions a working temperature of 150° C. may be sufficient, and the rubber itself can be allowed to come into contact with the blank.

Machineability

Magnesium alloys can be machined astonishingly freely and without lubrication. Their machineability is, in fact, greatly in advance of that of any other metallic material. It is possible, for example, to machine a D.T.D. type test bar 1 inch in diameter to finished form—0.564 inch diameter parallel portion—ready for pulling, with one cut. For this operation the test bar is rotated at a speed of about 3,000 r.p.m., and the total time for machining the test bar is about 60 seconds.

In commercial practice the machining of magnesium alloy components may be assisted by the use of jets of compressed air to keep the cutting edges cool. The fire risk in turning magnesium alloys is negligibly small, provided that the cutting tool is kept sharp and that heat is not allowed to develop by friction. The inflammability of small pieces of magnesium only becomes dangerously great when the particle size

is greatly reduced. Thus magnesium powder, the particle size of which is near 240 mesh, will rise in temperature only by a few degrees, even when wetted. Extremely fine particles of magnesium, of the order of 10^{-5} cm. in diameter, are, however, pyrophoric and even explosive on exposure to air.

The effect of surface finish of magnesium alloy test bars on their mechanical properties is sometimes described in technical literature. One Japanese paper went so far as to claim that a specially fine finish on a magnesium alloy specimen would be likely to result in an increase in proof stress of 50% and an increase in elongation of 100% over the figures obtained from a bar with an "ordinary" finish. Tests on the Elektron alloys have not confirmed such a general statement; it has been found that the mechanical properties of as-cast magnesium base alloys are only very slightly affected by variation between a "moderately rough" finish and a highly polished finish. With wrought magnesium base alloys the effect due to finish is more marked. Bars which are machined with a coarse feed, and are then polished by hand on the lathe, have been found to give results different from bars of the same material machined with fine feed and polished. The elongation was most affected; for the fine-finish bar the elongation was 50% higher; the ultimate strengths were found to be similar, and the proof stress was slightly lower.

These differences in the reaction of cast and wrought materials are in keeping with the already established observation that the notch sensitivity of wrought light alloys is greater than the notch sensitivity of the same alloys as cast.

Aircraft Applications

Many examinations have been made of crashed German aircraft scrap, and from these it has been found that the application of magnesium alloys, both cast and wrought, in German aircraft is very considerable. The alloys found in the German machines still appear to be of the standard Elektron compositions.

Many undercarriage parts, such as the undercarriage radius rod coupling, the undercarriage backstay, the undercarriage main spar bracket, and the tail wheel fork, have been found to be made in Elektron AZ91. This applies, for example, to the Heinkel 111.

The aileron control system also often carries magnesium alloy castings, and in the Heinkel 111 these parts are in the Elektron alloy AZG. Elektron AZM extrusions are also fairly widely used for such parts as the fuselage fitting carrying the tail plane and for the seat-raising control tube. Many machines, including the Heinkel 111, carry welded Elektron AM503 tanks for oil or for hydraulic fluid.

The Mes. 109 and 110 contain many magnesium parts and much magnesium sheet. The instrument panel in the Me.110 consists partly of Elektron and partly of Dural sheet. The undercarriage fairing is AM503 sheet. The engine bearers are forgings in Elektron AZ855 (8% Al, 0.4% Zn, 0.2% Mn).

The Junkers Ju88 also contains a number of magnesium parts, such as the main undercarriage mounting and retracting brackets, the rudder pedals, and all light alloy castings in the control system, including control stick, universal joint links, and hydraulic cylinders.

Magnesium alloy core-boxes and moulding boxes are very well known, and are used in many foundries for their lightness and durability. Die-cast magnesium alloy binocular frames are also well known, and have been standardised for some models by Zeiss. There have also been a number of applications of magnesium alloy parts for reciprocating or reversing revolving parts on high-speed machinery where low inertia is of importance. This applies particularly to the textile industry.

The use of press dies in Elektron alloys was increasing in the last few years, an application which was useful on account of the material's machineability and light weight. Assembly jigs of large dimensions have also been used in the aircraft industry; in the form of castings, these have the merits of rigidity and lightness.

NEW USES OF ELEKTRON SHEET

There has been a tendency amongst some aircraft manufacturers to take the line of least resistance and attempt to achieve weight-saving in aircraft components by substituting alloys of lower specific gravity for the heavier metals or alloys previously used, while retaining the constructional methods and general technique employed with the latter.

It is a curious but important fact that newly developed metals, possessing advantages either of strength or lightness, can be used only at the cost of greater care taken in their manipulation. This may be explained in some measure by the teething troubles common to all new materials, and by the trial and error methods which must necessarily be adopted when handling them, until the most practical method has been discovered and established in daily use.

Stainless steel, high-tensile strip steel, high-strength age-hardening aluminium alloys, such as Duralumin, and, of course, magnesium alloys, illustrate this statement.

The Introduction of Magnesium Alloy Sheet in the Production Shop

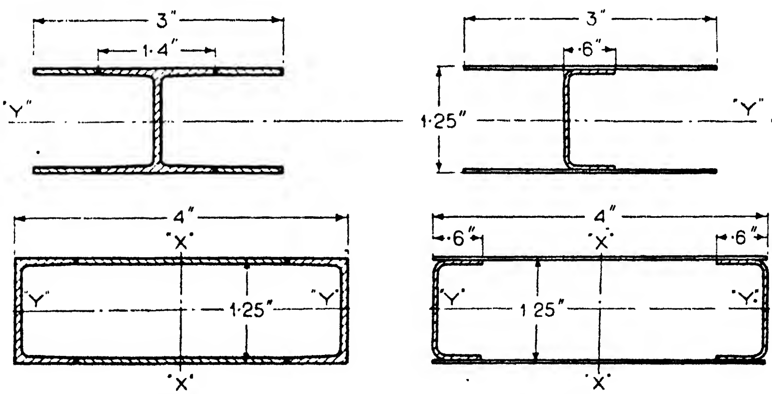
When magnesium alloy sheet was first introduced to the aircraft industry the difficulties of manipulations at first created considerable resistance to its use. Production shops, for instance, did not take kindly to the necessity for hot working, neither did they welcome the fact that rivet dimpling must be carried out warm, and that De Bergue riveting was practically impossible.

They were apprehensive when told that magnesium sheeting, when stored, must be well protected, and that it should be chromated or otherwise protected if left aside for a few days in the semi-fabricated state. Thus little feuds arose between the production shops and design offices of aircraft firms introducing magnesium alloys for the first time.

Many of the firms concerned are now well acquainted with the characteristics of magnesium in sheet form. From time to time they still encounter difficulties, many of which may be resolved by exploiting particular properties of the material, and difficulties also encountered in other metals, but which cannot be overcome in a similar manner. Certain problems still remain, however, and it is the purpose of this article to indicate their nature and suggest a satisfactory solution.

Difficulties in Production Shops

When confronted with a piece of structure, made in aluminium alloy, which has to be reduced in weight, a designer is strongly tempted to retain every detail of the existing design and merely to substitute magnesium sheet for aluminium.



(Above)—15 gauge sheet and section. Modulus Z_{yy} = .25.
(Below)—14 gauge sheet and section Modulus Z_{yy} = .38. Modulus Z_{xx} = .76.

(Above)—18 gauge section and 20 gauge. sheet Modulus Z_{yy} = .16.
(Below)—18 gauge section 20 gauge sheet Modulus Z_{yy} = .24. Modulus Z_{xx} = .55.

Fig. 62.—Comparison between structures in magnesium alloy D.T.D. 118 *and* 142 (*left*) *and in L.*3 *aluminium alloy.*

The piece of sheeting in question may be, for example, the covering of a bomb door The bomb door is made in the conventional manner by riveting the covering on a framework of angle or channel stiffeners. As the outside of the bomb door forms part of the fuselage surface, dimple rivets will probably be used. If the covering was originally made from a high-strength aluminium alloy the rivets may be placed very near to the edge of the sheet. If the rivet material used is hard the riveting machines will be adjusted accordingly.

It is obvious, therefore, that when the shops are called upon to substitute magnesium alloy sheet for the high-strength aluminium alloy sheet covering, they may discover that not only will the new covering be in a material of which they know little or nothing, but the gauge of the new covering may have been reduced on the grounds that the primary loads it may have to take are almost negligible. The shop foreman may, therefore, be confronted with the following difficulties when he applies to the magnesium sheet the standard technique for aluminium :—

(*a*) Magnesium alloy sheet will crack during working if the bomb door covering has considerable double curvature.

(*b*) Magnesium alloy sheet will crack when dimpled.

(*c*) The rivets, which should now have been changed from, say, Duralumin to the softer M.G.5 alloy, will yield too easily to the rivet punch adjusted for the harder rivets and the sheet under the riveting head will be deeply embossed.

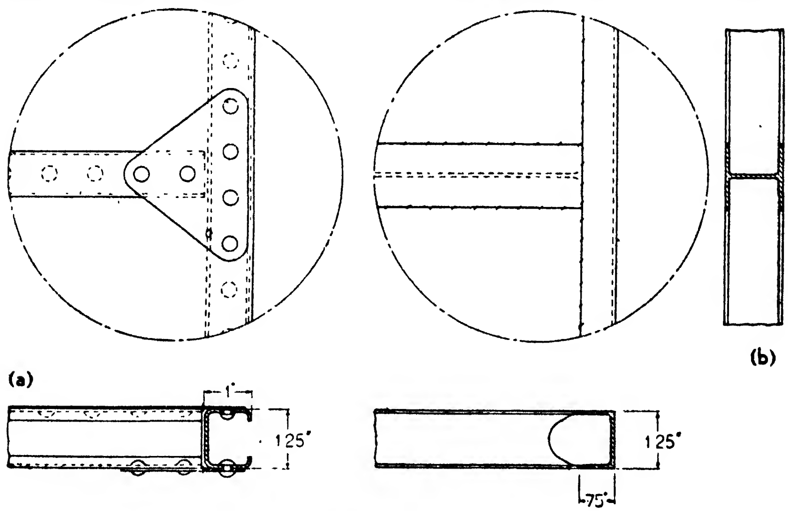
(*d*) If the bomb doors have been stored for some time, and particularly if insufficient attention has been paid to insulation between the covering and stiffeners (still in the original aluminium alloy), some oxidisation or corrosion may have started; the magnesium sheet covering, owing to its comparative softness, may have become scratched either during working or storing.

These imperfections may be noticed by a keen examiner, but if not, they will certainly be discovered when the aeroplane has been in service for a short time.

To ensure that they shall not recur the designer may then issue detailed instructions as to how the material is to be handled, and he may also adjust his riveting procedure. These measures will certainly eliminate the main difficulties, if correctly carried out, but they will not necessarily provide a permanent solution.

Designing for Magnesium

It is natural, though rather unfortunate, that some designers should still employ magnesium merely with the object of reducing weight, and that they should endeavour to achieve this end by the direct substitution of magnesium for a heavier metal and



(a)—Aluminium alloy framework of 18 gauge rolled section with 20 gauge magnesium alloy sheet covering and an 18 gauge aluminium alloy gusset. Weight of structure in circle, .39 lb.

(b)—Advocated design making use of interwelded heavy gauge magnesium alloy sheet and section. The covering is of 16 gauge magnesium alloy sheet. Weight of structure in circle, .23 lb.

***Fig.* 63.—Comparative weights of a typical bomb-door joint obtained with different methods of construction.**

without any regard to the more subtle methods of securing the same result, or to the other advantageous properties of the metal.

A structure which incorporates magnesium sheet should be designed accordingly, and in such a way that other advantages of the material, besides that of low weight,

can be exploited. For instance, suitably applied, the exceptional welding properties exhibited by a material possessing the mechanical strength of "Elektron" AM.503 can be used to great advantage. The capacity of this alloy in sheet form to deep draw at elevated temperatures is a useful characteristic, and one which at present is used to a limited degree.

The Use of Heavy Gauge Sheet

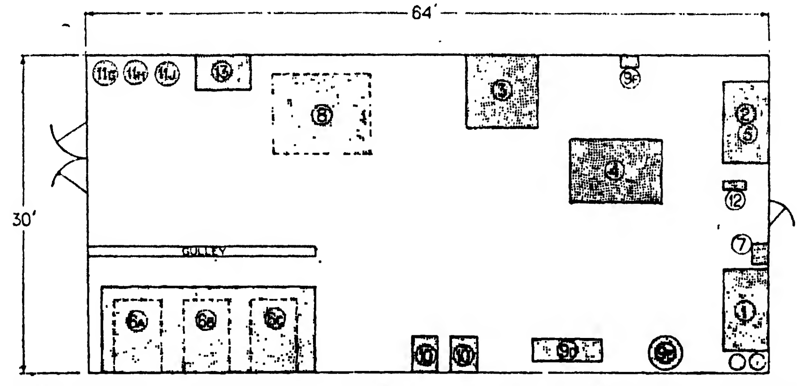
The designer should not overlook the possibility of using "Elektron" sheet in a heavier gauge than would be normal with an aluminium alloy, weight being nevertheless reduced as a result of the simplification of the internal structure which the greater stiffness makes possible. The use of magnesium sheet in this manner at correctly selected sites will obviously result in considerable saving of labour; in fact, in many cases designers introduce magnesium sheet for this purpose alone, the original finished weight of the structure as made in aluminium alloy being maintained.

As an example of this type of structure, consider a possible tail fin made wholly from "Elektron." In this case the skin is taken as 16 gauge, stabilised by H-section extrusions. Shear plates, pick-up brackets and rudder hinge pin mountings are bolted to the inner flanges or webs of the extruded sections.

This arrangement is approximately as strong and stiff as would be a similar fin made in aluminium alloy in the conventional manner, the lower modulus of elasticity of magnesium being countered by the greater mass of the individual pieces. The bigger scantlings used throughout will also help to reduce distortion which may be caused by welding, and the finished design is certainly simpler internally than would be the corresponding conventional one.

Structural Comparisons

Comparing aluminium and magnesium structures, heavy gauges and welded joints may be used for magnesium against light gauges and riveted joints in aluminium. The aluminium and magnesium constructions are equal in weight, strength and deflection, the higher section modulus of the magnesium cases balancing the lower value of its elastic modulus "E." As stability is usually the criterion of serviceability in framework of this kind, and as this property is achieved mainly by the stability of the comparatively heavy sheet itself, it follows that the intervals between the stiffening



1, welding bench; 2, work bench; 3, hot plate; 4, surface plate; 5, hand heater (gas burner); 6, (a) acid chromate bath, (b) hot water bath, (c) 5% chromate bath; 7, sink with running water; 8, 50-100 press; 9, (d) lathe, (e) drill, (f) grinder; 10, tool cabinets; 11, (g) sheet cutting scrap, (h) swarf, (i) bar and solids scrap; 12, bench shears; 13, sheet cuttings rack.

Fig. 64.—Proposed layout of an experimental shop for the working of magnesium alloy sheet.

sections may be considerably increased. This in itself will result in a slight saving in weight without necessarily involving a corresponding decrease in the primary strength of the panel as a whole. The full exploitation of this advantage will depend, of course, upon the careful location of the stiffening members.

The fin can be made in halves to ensure good access for the main welding operations; the two sides are then bolted together internally, and the leading-edge is finally welded

on. Whether or not the fin will be lighter than the conventional structure is difficult to determine, but such would probably be the case by comparison with a design incorporating an aluminium alloy covering in 18 or 20 gauge and more complicated internal stiffening. There is no doubt that the construction would compare with marked advantage in respect of labour economy, handling efficiency and, not less important, surface accuracy and regularity.

A simple junction—such as may be found in a bomb door design—may be constructed more lightly in relatively heavy gauge magnesium sheet and section than by the more conventional system using an aluminium alloy framework with a light gauge covering of magnesium. With an aluminium covering, of course, the difference in weight would be even greater.

Organisation of Production Department

The shop superintendent, like the designer, should regard magnesium sheet as a material distinct from the other light alloys. He knows that his sheet metal workers are experts in working, riveting and welding the standard aluminium alloy sheet materials, and it is not reasonable to expect them willingly to familiarise themselves with magnesium sheet—how to weld, how to work hot, how to rivet and how to protect the material—reverting then to aluminium, and so alternating between the two techniques in a workshop crowded with the tools necessary for each material. It is unquestionably more economical and satisfactory for magnesium sheet to be treated as a special job, and for the tools, appliances and labour to form a separate section in the shop.

The equipment required should include apparatus for heating the sheet by gas or electricity, for dishing, drawing, bending, riveting and welding. There should be the necessary washing and chromating baths, drying equipment, insulating and painting materials, and the men should become as expert in the use of these accessories as they already are in the handling of the appliances of the aluminium shop. Given these conditions properly trained men can turn out magnesium components as rapidly and as efficiently as parts made in aluminium.

General

Here, then, in brief outline are the essentials of a more economical and satisfactory technique for magnesium alloy sheet. It is to be expected, of course, that they will meet with the criticism which is always reserved for new and untried methods; but the soundness of the principles described, particularly in so far as they affect weight and simplification of design, is confirmed by the results obtained in the design and manufacture of "Elektron" tanks and other more highly stressed structures, and it is only when comparison is made between the weight figures for similar components made in the more conventional manner from aluminium alloys, that the large volume of material employed in rivet and bolt heads and flanges of stiffeners becomes evident. The results of such a comparison are worthy of attention.

PRACTICAL HINTS ON THE WORKING OF ELEKTRON SHEET

ELEKTRON sheets are supplied in the fully annealed condition and only a very limited amount of bending or shaping can be carried out in this condition at ordinary temperatures. The following figures will serve as a rough guide as to the minimum radii over which Elektron sheet may be bent cold:

Alloy	Thickness S.W.G.	Min. Bending Radii inch
AZM	23	0.125
	19	0.250
	17	0.437
	14	0.750
AM.503	23	0.104
	19	0.250
	17	0.437
	14	0.750

All shaping calculated to exceed the severity of the bends given above must be carried out hot.

The optimum temperatures for hot working are :

For AM.503 .. .. .. From 270° to 330°C.
For AZM .. .. .. From 270° to 300°C.

The slightest appearance of cracking at bends—even skin cracks—must be avoided, as these, when subject to alternating stress, are liable to lead to fracture. It is considered good practice if, for hot working, the bending radius is never less than twice the sheet thickness.

When shaping or forming is carried out, as in the fabrication of cowlings or tank bodies, the best practice is to beat to shape over a wooden former, using a blowlamp, air and gas or acetylene flame. A simple method of determining the correct temperature is to apply to the sheet a few drops of lubricating oil having a flash point of about 300°C. When the oil flashes, it will be found that the most suitable temperature exists for the deformation of the sheet. For heavy deformations, the best practice is to do a little at a time, annealing with the flame, as required. The heat loss when using wooden formers is comparatively small and a considerable amount of work can be done in one heating. If metal formers are used, then it is essential that these be brought up to the working temperature of the metal and, as far as possible, maintained at that temperature. In deep drawing and pressing operations, it is desirable to raise the tools to a temperature higher than the working temperature, say from 400° to 450°C., in order to avoid any chill to the metal as it comes into contact with the tools. In deep drawing operations, and, indeed, in all deformation processes on Elektron, the slower the speed of deformation the better.

Welded joints which have been well made and hammered after welding can be formed just as well as unwelded sheet.

Applications

Elektron	D.T.D. Specification	Application
AM.503	118 Sheet 142 { Bar, Sections	Cowlings, fairings, linings and bulkheads, fuel and oil tanks, flaps, rudders, etc., and those applications where ease of working and welding are of major importance. Always specify AM.503 for extensive welding in sheet, tube or extruded section.
AZM	120A Sheet 259 { Bar, Sections	Stressed parts where strength is more important than ease of working or welding. For stiffeners and struts in tank and cowling fabrication, fixed by riveting. Not recommended for extensive welding. Welds satisfactorily for short or point welds to itself. Do not attempt to weld AZM to AM.503.

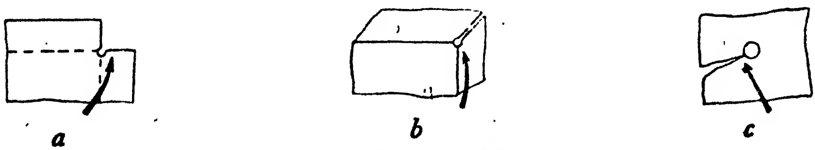


Fig. 65.—Bending Radii of Elektron Sheet.

Always work Elektron hot : 270° to 330°C. Use air—coal-gas blowpipe, blowlamp, hot air-blast, muffle furnace or outer zone of welding flame, etc. Useful temperature controls :

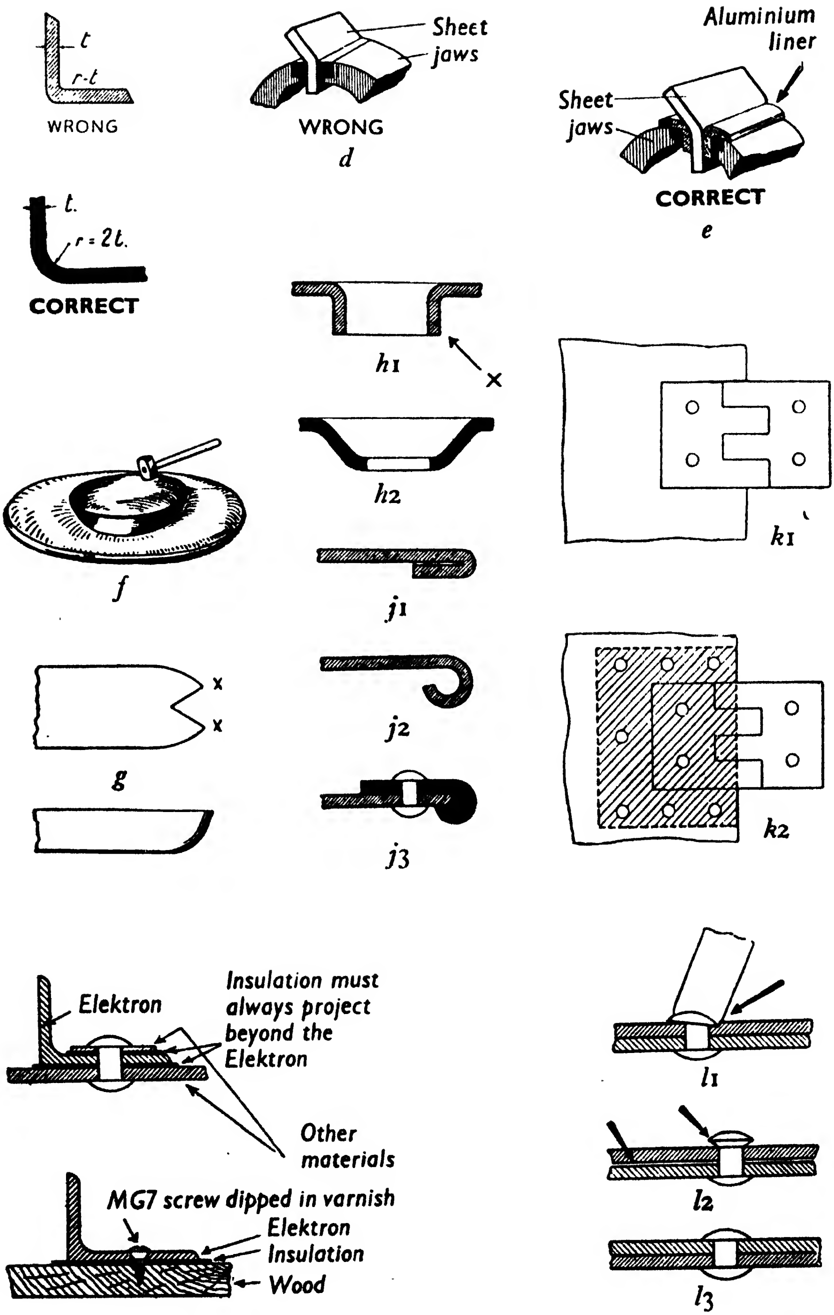


Fig. 66.—Hints for working Elektron Sheet.

(*a*) Machine oil touched on to the work flashes at 300°C.
(*b*) Wood touched on to the work will char at 300°C.
(*c*) Blue crayon turns brown at 300°C.

Bending Radii
must never be less than twice the thickness of the sheet. See that no cracks occur on the back of the bend. In bending, drill out corners and fraze edges as shown in Fig. 64, *a* before and *b* after bending. Cracks should also be drilled out at their extremities, frazed and welded up *c*. If welding be impossible, after drilling and frazing, plate both sides and rivet up.

In bending in the vice, see that the jaws are well insulated with wood or aluminium sheet, to prevent damage to the Elektron surface, when bending over a sharp corner *e*, in Fig. 66.

Beating

Use the sandbag in the usual way but be sure that the work is hot.

It is a good principle in working Elektron to remember that it welds much more easily than it beats, and frequently much time can be saved in deep beating by previously slashing, bending and welding as shown at *g* of Fig. 66. With the sheet suitably cut, bring the points x-x together, weld, and rectify by beating to the finished form.

NOTE: Planish the weld by hot hammering before beating to finished form.

Flanged Holes

Flanged holes of *h*1 type in Elektron are very difficult to make and run the risk of cracking at x. Type *h*2 is much better and should be adopted wherever possible.

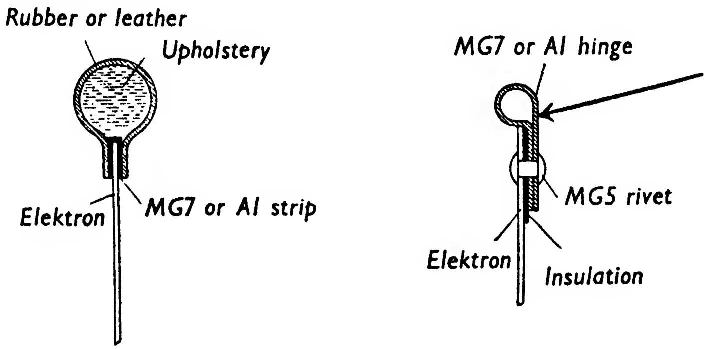


Fig. 67.—Method of wiring Elektron to other materials.

Beaded or Wired Edges

Beading by the method *j*1 is not recommended for Elektron. It is seldom successful The method *j*2 is possible but expensive.

*j*3 shows the best method: an extruded bead section is riveted or welded to the sheet edge. This method satisfies most requirements, but should a wired bead be essential, adopt *j*2 with MG5 or MG7 wire. No other material should be used for wiring.

Attachment of Hinges, etc.

The method *k*1 is bad practice; the sheet is not reinforced.

The method *k*2 is good practice; the sheet is well reinforced and plenty of well-spaced rivets are used.

Riveting

If the diameter of the rivet = D, then the distance between the edge of a sheet and any rivet must never be less then 2D.

The distance between any two rivets or line of rivets must never be less than 3D.

Use only MG5 Rivets

Gauge of sheet (S.W.G.) ..	24-21	20-16	15-12	f11-6
Diameter of rivet	$\frac{3}{32}$ in.	$\frac{1}{8}$ in.	$\frac{3}{16}$ in.	$\frac{1}{4}$ in.

In riveting the greatest care should be taken to avoid the conditions of *l1* and *l2* and ensure that all joints are like *l3*. This is more important in Elektron than any other material.

Riveted seams should be chromated as a primary protection against corrosion. Riveted joints of several members should, wherever possible, be chromated before riveting together and the completed joint chromated after assembly.

Insulation

Wherever it is necessary to join Elektron to other materials like steel, copper, brass or wood, the Elektron should be suitably insulated from these materials. Insulation is not necessary in contact with MG7 and pure aluminium, with which metals Elektron has the minimum electrolytic action.

The following may be used as insulating materials: varnishes and lacquers, heldite, marine glue, osotite cement-glue, etc.; synthetic resin and plastic products generally; micarta, oiled linen or silk, langite, rubber or chrome-free leather.

Where it is desired to join such materials as leather or aircraft fabric Elektron, cement-glue is the best adhesive, as this admits of supplementary impregnating or varnishing.

Tubes or hollow sections of this type, and closed corners, must be chromated and varnished *inside*. It is best either to close them completely or deliberately to drill them to permit ventilation and outlet of moisture or water.

Elektron AM.503 Sheet for Aircraft Fuel and Oil Tanks

Elektron is now very extensively used in the aircraft industry for the manufacture of cowlings and fairings on engines, wings, and fuselages. It is at present being developed in the form of tanks.

So far as oil tanks are concerned, it may be used with the greatest confidence without any protection except the usual chromate finish, and it is in every way an ideal material for this use.

For Elektron fuel tanks, certain precautions are necessary if the use of doped fuels (TEL) is contemplated. Although fuels doped with tetra-ethyl lead do not attack Elektron except in the presence of water, since in practice water is always present it is necessary to provide against this attack suitably.

This provision is possible by insertion at the lowest point in the tank, considered when the aeroplane is at rest, of a corrosion inhibitor cartridge. This consists of a perforated metal cage containing a small canvas bag in which is placed a mixture of specially prepared salts which affectively dehydrate the fuel in this region. These inhibiting salts are sold by Messrs. F. A. Hughes & Co., Limited, and only by them, in bags of suitable size for 25, 50, 75, and 100 gallon tanks, but special sizes can be supplied if required. The inhibitor arrangement is shown on the following page and, although the precise design may vary with each type of tank and is really a matter for the constructor or tank-maker to determine, this illustration shows one successful type of unit.

It is important that the bottom row of perforations in the inhibitor container should be considerably below the bottom of the tank at its lowest point. The size of the inhibitor container is roughly determined by the Air Ministry requirement that 1½ oz. of the inhibiting salt must be provided for every 100 gallons of fuel. With large tanks, it is better practice to put two or more inhibitors at points where the fuel will have unrestricted flow to them from all directions, rather than to rely upon one large unit which may be baffled off from certain sections of the tank. The salts supplied by Messrs. F. A. Hughes & Co., Limited, are selected for constant solubility and carefully prepared for high purity, because certain impurities tend to produce corrosion.

The life of a cartridge of inhibiting salts must be judged by the condition of the tank in its usual frequent inspections, and the cartridge renewed at the first signs of attack. For ordinary flying service over land, renewals may be necessary at about yearly intervals. If a tank is for any reason taken out of service and after storage put back into service, cartridges of fresh salts should be inserted at that time.

Not only does the quality of the inhibiting salts demand that they be obtained only from Messrs. F. A. Hughes & Co., Limited, but these are the only salts which have Air Ministry approval for use with magnesium alloy tanks.

Welding of Wrought Alloys

Elektron may be successfully welded by the oxy-acetylene flame. Given the correct flux and welding rod, the achievement is a matter of manipulative skill on the part of the welder. Highly skilled operators are the first essential to success in acquiring a technique not more difficult, but far more precise in detail, than is necessary with the welding of aluminium, for example. Once acquired, though, Elektron may be welded with all the facility of aluminium or steel and it is possible to obtain very high strength efficiency and durability in the welds.

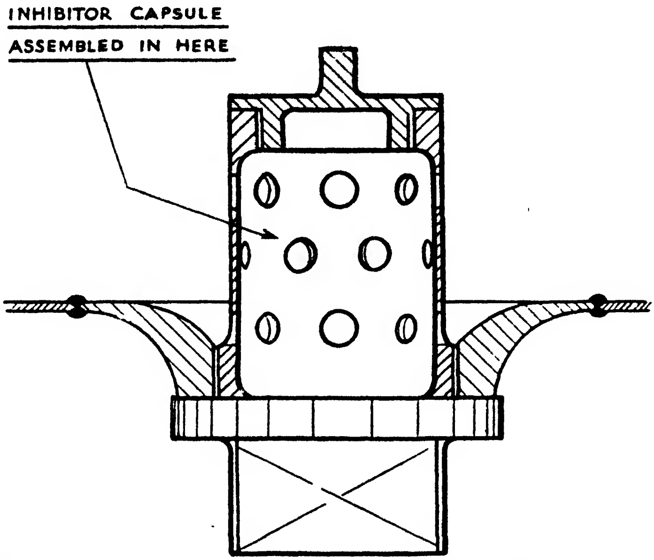


Fig. 68.—One satisfactory arrangement of Corrosion Inhibitor Container for Elektron Fuel Tanks.

Arrangements have been made with the British Oxygen Company, Ltd., of Thames House, Millbank, London, S.W.1. (and their branch factories), for the supply of all welding rods and fluxes used in the welding of Elektron. The British Oxygen Company will be pleased to supply full descriptive matter on welding materials and equipment and also to arrange through their service department demonstrations of Elektron welding to interested parties on request.

The Elektron alloy AM.503 lends itself to welding, whether in the form of sheets, tubes, sections or machined parts. All tanks and cowlings are made from AM. 503.

The alloy AZM is weldable also, but less easily. Very successful work may be done with this alloy in the construction of seats, luggage racks and the secondary furnishings for aircraft in the popular tubular designs, where the welds are essentially short. Such products have astonishing strength and lightness.

For welding AM.503 specify welding rod " AM.503."

For welding AZM specify welding rod " AZM."

Instructions for Welding Wrought Elektron

1. Weld preferably by the oxy-acetylene process.
2. Weld AM.503 only to itself.
3. Weld AZM only to itself.
4. Do not attempt a weld between AM.503 and AZM.
5. For welding AM.503 use welding rod of AM.503.
   For welding AZM use welding rod of AZM.

List of Tubes (Alloys AZM and AM.503)

The minimum wall thickness is a function of the diameter and must be appropriate thereto. The following table gives the standard sizes for which tools exist. Tools can be made from a minimum of ⅜ inch diameter to a maximum of 8 inches diameter, with appropriate wall thicknesses.

Outside Diameter inches	Wall Thickness inches	Approximate Weight per foot lb.
0.433	0.059	0.063
0.500	0.062	0.077
0.511	0.059	0.075
0.590	0.059	0.086
0.625	0.064	0.100
0.748	0.059	0.110
0.846	0.064	0.134
0.866	0.075	0.161
0.875	0.064	0.140
0.875	0.080	0.173
0.875	0.122	0.264
0.925	0.065	0.150
1.000	0.064	0.160
1.125	0.064	0.180
1.250	0.064	0.200
1.300	0.122	0.400
1.300	0.132	0.420
1.300	0.148	0.480
1.500	0.128	0.475
1.610	0.079	0.315
1.750	0.128	0.560
2.000	0.080	0.400
2.000	0.128	0.640
2.125	0.080	0.420
3.125	0.437	3.400

Tolerances

On the outside diameter, ± 2.5% of the nominal diameter, with a minimum of 0.010 inch.

On the wall thickness, ± 10% of the nominal thickness.

These tolerances result from the fact that Elektron tubes can be manufactured only by hot working processes and cannot be cold drawn. They will hold for all tube products, unless in special circumstances closer tolerances are undertaken and specified on the order.

PLASTICS IN AIRCRAFT CONSTRUCTION*

By GEORGE W. DeBELL

MANY engineers look upon plastics and allied materials as entirely new to the aircraft industry, but such is not the case. Phenol fibre sheet and resin-bonded waterproof plywood have been used for years, and acrylic resin sheet has been in use for transparent enclosures for some time past, yet all come under the above category. The primary difference between the past and present uses of these materials is that they are now used in applications where structural loads are involved, while they were previously used only in non-stressed parts, where special characteristics, such as transparency or insulating qualities, were of paramount importance. If these materials are classified according to their major characteristics, they fall into three categories, namely, those

* Paper presented at the annual meeting of the Institute of the Aeronautical Sciences, New York.

made with thermosetting resins, those made with thermoplastic resins, and those made with wood veneer. This classification also in a general way divides them according to their principal uses, thermosetting materials being used mostly in the production of relatively small structural parts, the thermoplastics being used mostly for their transparent properties, and the wood veneer materials being used mostly in relatively large structural parts and assemblies.

Thermosetting Materials

The thermosetting materials, as their name implies, are materials manufactured with resins that, upon complete polymerisation, become infusible solids that will not soften when heated. The polymerisation of this class of resin can be attained in either of two ways: by the initial application of heat or by the use of a chemical accelerator. Polymerisation by means of heat is the method in general use, with the exception of the cold-setting resin adhesives, which are generally completely cured by the introduction of a chemical accelerator, although in certain instances a minor amount of heat is essential to complete cure.

A majority of the thermosetting materials used in aircraft is manufactured with the phenol formaldehyde resins, although urea formaldehyde and melamine resins are used in certain instances. The melamine resins are relatively new and are at present used only as thermosetting surface coatings where their permanent transparency is a distinct advantage. The major use of the urea formaldehyde resins in aircraft is as adhesives, but they are also used in applications where a thermosetting material is needed and where light colours are essential, since the phenol formaldehyde resin has an inherent mahogany brown colour that prevents its use in such applications.

Large quantities of low-impact phenol formaldehyde materials are used commercially in the various non-defence industries, but this class of material has only a limited application to aircraft, since its low impact strength precludes its use in all applications where there is the slightest danger of accidental damage. It is therefore relegated largely to the manufacture of control knobs and like parts. The high-impact phenol formaldehyde materials have, however, mechanical properties that justify their extensive use in aircraft where the structural loads are not excessive. Such applications as radio masts, control quadrants, brackets in the bomb release system, equipment support brackets, and housings are well within the design limits of this material. Although this material might possibly be utilised for the manufacture of primary structural units, such as control columns and highly stressed brackets in the primary control systems, it is not felt that our design knowledge has progressed to the point where such applications could be safely undertaken without extensive design research and static testing.

Three methods are used for manufacturing parts from this material: they may be machined from sheet, tube, or bar stock, they may be moulded from laminated material, and they may be moulded from high-impact moulding material. The first method has been used for years and needs no discussion. The second method consists of impregnating sheets of cloth or paper with the uncured resin and forming and curing the desired number of layers of this material to the required shape in heated steel dies. Since the cloth or paper sheets used can only be formed or stretched to a reasonable degree without tearing, this process is limited to relatively simple shapes, such as channels, angles, and shallow pans. The third method consists of impregnating macerated or shredded fabric with the uncured resin, then pouring the impregnated material into the cavity of a heated steel die and curing and moulding to the desired shape under high pressure.

Thermoplastic Materials

The thermoplastic materials consist of those fully polymerised synthetic resin materials that will soften and become plastic upon application of heat. Under this classification fall the acrylics, notably " Plexiglas " and Lucite," the cellulose acetates, polystyrene, the vinyls, and others too numerous to mention.

At the present time the acrylics are by far the most important from an aircraft standpoint, although there is a possibility that in the near future some of the cellulose acetates and vinyls may also be used to an appreciable extent. The greatest use for these materials is in transparent enclosures where their clarity, combined with light weight, is of sufficient importance to offset their low scratch resistance and variation in strength with temperature. They can also be used to a limited degree in internal non-stressed parts, such as control knobs, instrument dial faces and placards, where their high rate of change of strength with temperature is of little importance. They

should not, however, be used in any stressed application unless a thorough analysis has been made of the temperature effects. In this regard the effects of the radiant heat of the sun should be carefully considered and taken into account. One of the principal reasons that these materials have proved successful in transparent enclosures is that because of their high light transmitting efficiency they do not absorb the radiant heat of the sun to the same extent as dark coloured or opaque materials, and therefore attain a temperature only slightly above that of the ambient air. However, if the thermoplastic materials are used in opaque form or are mounted in intimate contact with opaque surfaces, their temperature will rise appreciably because of the effects of radiant heat, and this rise in temperature will be accompanied by a marked lowering in some of their physical properties and in their resistance to cold flow.

Two methods are used for manufacturing parts from these materials: (1) sheet stock is heated until soft and stretched over forms of the desired shape or is pressed in the desired shape in heated dies; and (2) granulated material is moulded to the desired shape in heated dies of either the compression or injection type. In either process the material must be cooled before being removed from the form or die in order to prevent distortion while the piece is being stripped.

Wood Veneer Materials

Wood veneer materials are normally supplied in the form of either flat or moulded plywood, in which the grain of adjacent plies is crossed, or in the form of laminated wood, in which the grain of all plies is parallel. The material may be supplied either impregnated or unimpregnated, but up to the present time almost all the material is of the unimpregnated type, the impregnated wood veneers being limited mainly to propeller blanks. The unimpregnated wood veneer materials are generally bonded with a thermosetting synthetic resin adhesive, although thermoplastic adhesives have been used to some extent. For maximum durability and resistance to moisture, hot-setting adhesives of the thermosetting type are preferred. Wood veneer materials made with the cold-setting thermosetting adhesives are believed to be slightly inferior under extreme conditions of moisture and heat, but within the normal aircraft operating range it is felt that this inferiority will not be evident. The best combination of serviceability and manufacturing facility can be attained by using hot-setting thermosetting adhesives for the manufacture of the plywood sheets and the cold-setting thermosetting materials for the manufacture of the heavy frame members and for assembly.

When the hot-setting type of adhesives is used in the manufacture of heavy members there is always the danger of damaging the wood by excessive heat, since the curing time is a direct function of the thickness of the member. Serviceability of the thermoplastic adhesives in aircraft construction has yet to be conclusively proved, since there is still considerable question regarding the effect of cold flow of the adhesive at the maximum temperatures which may be experienced in tropical service. Existing information on this subject is contradictory, and it is therefore recommended that when such thermoplastic adhesives are used extreme care be exercised to ensure that the glue lines are not highly stressed. Plywood made with such adhesives will probably, in most cases, be satisfactory, since the stress in plywood glue lines are usually low, but in framing joints this is not usually the case. The thermosetting adhesives available at present are of the phenol formaldehyde and urea formaldehyde types and are offered in both cold and hot-setting varieties. The thermoplastic adhesives in use at present are usually based on the vinyl resins or cellulosic compounds. Casein, blood albumen, and other protein plastics should, in general, be avoided as they are subject to bacteria and fungus attack, which cannot be conveniently detected until failure occurs. Such attack of the protein plastics is prevalent in hot humid climates as would normally be experienced when operating in the Tropics.

Impregnated wood veneer materials for general use in aircraft construction are just now becoming available, but their utilisation and further development should be sponsored to the maximum possible degree, since they are much stronger and stiffer than the ordinary laminated thermosetting plastics and can be moulded at appreciably lower pressures. The Forest Products Laboratory research on these materials has indicated that by proper impregnation the ultimate swelling due to moisture absorption can be reduced to somewhat less than one-third of the swelling of normal unimpregnated wood and that the rate of moisture absorption and swelling can be reduced many fold. Their research also indicates that this reduction in ultimate moisture absorption and swelling is practically independent of the density of the resulting material; for example, starting with spruce veneer, impregnated materials can be produced of any density from 0.6 to 1.5. The physical properties of these materials will, in general, vary almost

directly with the density, although the increase in certain factors is, of course, not quite so rapid. Laboratory samples of material having 1.4 density have indicated tensile strengths as high as 50,000 lbs. per sq. inch, compression strengths are in the neighbourhood of 35,000 lbs. per sq. inch, and moduli of elasticity are in the neighbourhood of 4,000,000 lbs. per sq. inch.

Design Considerations Affecting Utilisation

If the foregoing materials are to be successfully utilised, it is essential that the basic design of the parts be established by engineers who are fully cognisant of the aircraft manufacturing and operating problems, of the plastic manufacturers' problems, and of the physical properties of the material under consideration. Such design control can be accomplished in any of three ways: (1) the design can be turned over entirely to the plastic manufacturer for development; (2) the design can be handled by the aircraft manufacturer working in co-operation with a particular plastic manufacturer; and (3) the design can be handled completely by the aircraft manufacturer.

The first method does not offer much hope of success, since few, if any, of the plastic manufacturers employ engineers who are sufficiently skilled in the manufacturing

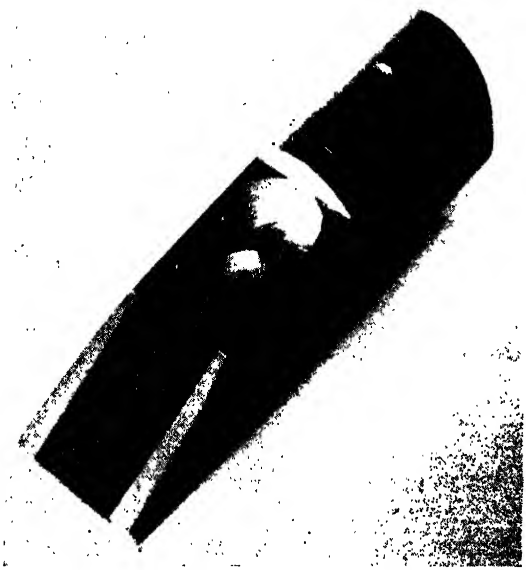


Fig. 70.—Aerial mast base machined from Bakelite laminated.

and operating problems of aircraft to produce a part entirely satisfactory from all standpoints. The second method has the disadvantage that the aircraft company must initially select a particular plastics manufacturer with whom to work on each particular application; this eliminates the advantages of competitive bidding and oftentimes the plastic manufacturer selected is not the best source for the part under consideration. Also, in this method there is a tendency to design the part around the existing equipment of that particular manufacturer, even though this may make for an inferior design. The third method appears to have the fewest drawbacks, in that a skilled aircraft engineer can, in a reasonable length of time, become familiar with the general problems of the plastic manufacturers and can then produce a design that closely meets the requirements of everybody concerned. The design can then be sent out for competitive bidding and the final details worked out with the company selected to manufacture the part.

Experience has shown that the first and second methods are much more time-consuming than the third, since much more *liaison* is required between the aircraft manufacturer and the plastic manufacturer. When the third method is used, design differences can generally be cleared up in a single conference, and on a majority of parts no conference at all is required. This procedure also makes for a more equitable distribution of responsibility, for the aircraft manufacturer is then responsible for the suitability of the application and its proper functioning and the plastic manufacturer is responsible for the integrity of the part itself from both a dimensional and materials standpoint.

Aircraft Factors Affecting Design

In order that plastics and allied materials may be utilised successfully in the manufacture of aircraft parts, several factors that are not normally considered in metal construction must be taken into account.

Temperature.—The most important of these factors is the effect of the operating temperature range. For a majority of aircraft parts this range is from 70° to + 160°F., the lower temperature limit being that which may be obtained in the Arctic or in the stratosphere, and the upper temperature limit representing temperature that can be obtained in the Tropics, including the effect of the radiant heat of the sun. This

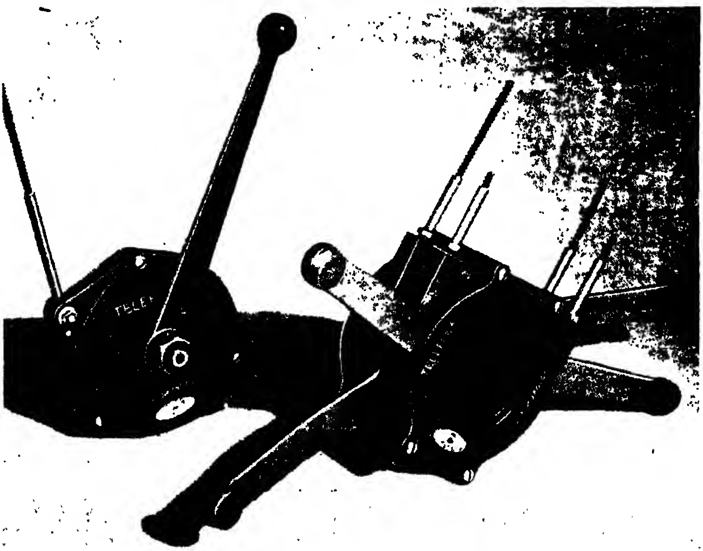


Fig. 71.—Teleflex controls machined from Bakelite laminated.

upper limit is not considered to be excessive, as 190°F. has been obtained in tests of road surface temperatures in Southern California. The relative effect of this temperature range on the tensile compressive and flexural strengths of the thermosetting and thermoplastic materials is shown in Fig. 73A. The effect of temperature on the unimpregnated wood veneer materials is slight, provided no change in moisture content occurs. It will be noticed that the thermoplastic materials have, in general, a much greater change in strength with temperature, but this is only part of the story, as they also have a much greater tendency to cold flow at the higher temperature limit and therefore the allowable stress at high temperature for the thermoplastics must be reduced even further than shown in the diagram on page 144.

Impact Strength.—The second important factor is the influence of the low impact strength of these materials on the possibility of accidental damage during installation and service. Although the thermosetting and thermoplastic materials are greatly inferior to aluminium alloy in impact strength, this does not indicate that they are inferior when

used in properly selected and designed aircraft parts. Their lower impact strength is, in most cases, offset by their lower density, which permits the use of sections at least twice as thick when designed in plastics.

Weight Requirements.—Many people have advocated the use of plastics on the basis of weight saving, and, although this is true to a certain extent, it should not be carried to extremes or the resulting parts will be too fragile and flexible for satisfactory service operation. In general, it is better to design the plastic part for a weight equivalent to that of its metal counterpart, and thereby avoid the possibility of producing parts that are unsatisfactory in service. Usually, if the draughtsman is told that the plastic part is to be made for a weight equal to, or less than, the equivalent metal part, he will produce a unit that is 5 to 10% under the allowed weight, yet perfectly satisfactory from a manufacturing and operating standpoint.

Resistance to Wear

The problem of wear on plastic parts can usually be controlled through proper use of inserts. In deciding where to put inserts, the designer should take into account the expected service life, the type of wear involved, the bearing stresses developed, and the type of lubrication which will be supplied. Wherever screw threads are called for, it is advisable to use inserts so that the threads will be entirely of metal, as plastic threads, particularly in the smaller sizes, are subject to chipping, and when tightened have a tendency to seize on the screw so that the plastic thread is destroyed when the screw is removed. It is, however, permissible to use plastic threads in certain instances where the thread is merely an assembly feature to simplify design, but in such instances an adhesive is usually applied to the threads so that the pieces cannot again be disassembled.

Plastics should be used for the bearings of rotating shafts only when the bearing stresses and speeds are low and when friction is not an important consideration; otherwise, it is advisable to use metallic inserts in such positions. In this regard, Oilite bushings may be used as moulded-in inserts, provided they are not filled with oil at the time of moulding. The porosity of this type of bearing provides an excellent bond between the insert and the plastic and at the same time the bushing only fills up with resin for a depth of about twelve-thousandths from the surface. After moulding, the part is then submerged in hot oil to impregnate the bushings. However, when such porous bushings are moulded into the plastic part, it is essential that the mould pins over which the bushings are placed in the mould be close fits for the bushings, otherwise there is danger of the resin running between the bushing and the mould pin and sealing the operating surface of the bushing.

In certain specific applications the thermosetting plastics have proved themselves superior to the metals as bearing materials. This is evidenced by the use of fabric-base phenolic laminated timing gears in the majority of automobile engines, and by the use of fabric-base phenolic laminated bearings in heavy rolling mill equipment. In the rolling mill application the bearings are lubricated with water, while in the timing gear applications they are, of course, lubricated with oil in the normal manner. When quietness of operation under vibrating conditions is desired, thermosetting plastics offer considerable value as bearing materials, provided due precaution is taken to ensure that the allowable loads are not exceeded and that adequate lubrication is provided. The aforementioned timing gear application comes in this category.

Coefficient of Expansion

When relatively large plastic parts are rigidly mounted to metal supporting structures, due account should be taken of the differential coefficient of temperature expansion of the two materials. It should be remembered that the parts may be assembled at 90°F. and then operated at −70°F., thereby producing stresses and strains equivalent to the differential coefficient of expansion times the temperature difference of 160°F. Such stresses and strains may be an appreciable percentage of the allowable stress and therefore care must be exercised to ensure that the sum of these stresses and the normal design stresses do not exceed the allowable. Oftentimes these temperature stresses may be eliminated or materially reduced by utilising a mounting method that permits relative motion between the plastic part and its metallic supporting structure. This relative expansion problem is not usually important on small plastic parts, such as brackets and fittings, but it definitely must be taken into account when designing large transparent enclosures, such as turrets, bomber noses, and pilots' enclosures. It is also more important when dealing with the thermoplastic materials than with the thermosetting ones, since the thermoplastics have a greater differential coefficient of expansion.

Moisture Absorption

The thermosettings, the thermoplastics, and wood veneer materials all absorb moisture, but to varying degrees. The thermosetting and thermoplastic materials are only slightly sensitive to moisture, and this factor may be ignored except in severe electrical applications or where dimensional tolerances are exceptionally close. Such is not the case when using the unimpregnated wood veneer materials, whose strength and dimensions vary noticeably with the moisture content. The effect of moisture on the unimpregnated wood veneer materials may be greatly reduced by the proper application of the high-grade synthetic resin finishes which have been developed over the last three or four years, but it should be borne in mind that no finish is entirely impervious to moisture, and therefore that even the best finishes merely reduce the rate of moisture absorption. Although these modern finishes offer adequate protection under fluctuating atmospheric conditions, they do not offer moisture protection when the atmospheric conditions maintain over long periods of time. For instance, if the finish was applied to the wood veneer piece in the northern part of the country under atmospheric conditions that would produce stabilisation at 8% moisture content, and the piece was then shipped to the Tropics, where the average atmospheric conditions tended to produce 15% moisture content, it could be expected that the part would eventually stabilise at 15% moisture content, although it might take six months to a year before this value was attained. If, however, the aeroplane on which this piece was mounted was moved to various parts of the country at frequent intervals, the moisture content of the piece would not materially alter, since the low rate of permeability of the modern synthetic resin finishes would protect against rapid fluctuations in humidity.

Although little research has been done to date on the moisture-absorption characteristics of the impregnated wood veneer materials, it is reasonable to expect that their sensitivity will be of the same order of magnitude as the thermosetting phenolic materials, since the impregnation protects the wood fibres to the same degree as the cotton fibres are protected in fabric base phenol fibre.

Relative Cost

The foregoing factors all pertain to the functional aspects of the application, but the analysis would not be complete unless the economic aspect were also considered. The thermosetting and thermoplastic materials are either moulded in steel dies under relatively high pressure or manufactured as sheet, tube, and bar stock that is fabricated by shearing, punching, and machining. At first glance it would seem that the attendant die expense would eliminate moulded plastics from consideration in the present aircraft quantity brackets, but such is not the case, because the metal parts against which they are competing are not manufactured by high-production processes, and also because in many cases one plastic part replaces an assembly consisting of several metal parts. Experience has indicated that moulded plastics usually can compete with strong aluminium alloy castings on a cost basis if the quantities involved are above 1,000, and that where the moulded plastic part replaces a complex assembly consisting of several metal parts, the cost will be in favour of the plastic on quantities of 300 or more. These figures are, of course, approximate, but serve to indicate the limits of the quantity brackets in which cost equality occurs.

The principal reason why moulded plastics compete in aircraft in such low quantity brackets is that the moulded plastic part comes out of the mould in its finished form, while the metal counterpart generally requires additional operations. The cost of fixtures and labour for performing these additional operations on the metal offsets the cost of the die for manufacturing the plastic part. The materials costs are usually about the same, any small difference being in favour of the plastics. It follows that where the metal counterpart would be relatively simple to manufacture, the quantities must be large before moulded plastics become economical, and that where the metal counterpart is relatively complex moulded plastics may be economically used in quantities of only a few hundred. In quantities smaller than those discussed, moulded plastics will be the more expensive, and should not be used except in applications requiring specific properties, such as electrical insulating value, heat insulating value, or transparency.

Although moulded plastic parts are uneconomical in quantities lower than 300 to 1,000, the same is not true of items such as transparent enclosures, which are made from thermoplastic sheet stock formed to shape, since the cost of the fixtures for forming the plastic sheet is relatively small. Frequently, by designing the transparent plastic parts to be self-supporting, it is possible to eliminate a great deal of the metal framing

used in transparent enclosure designs, and the savings made by this elimination more than offset the cost of the forming fixtures for the plastics, even when small quantities are involved.

With reference to the wood materials, the unimpregnated type is competitive with metal even in small quantities, since the cost of fixtures and tools for manufacturing formed plywood shapes compares favourably with the cost of metal fixtures and tools in like quantity lots. The wood veneer materials of the unimpregnated type may therefore be used in any quantity bracket that would be contemplated for metal construction. There are not sufficient data available to draw any conclusions regarding the economic quantity brackets pertaining to the impregnated wood veneer materials, but it is reasonable to assume that the quantities will fall approximately midway between economic quantities for moulded plastics and those for unimpregnated wood veneer materials.

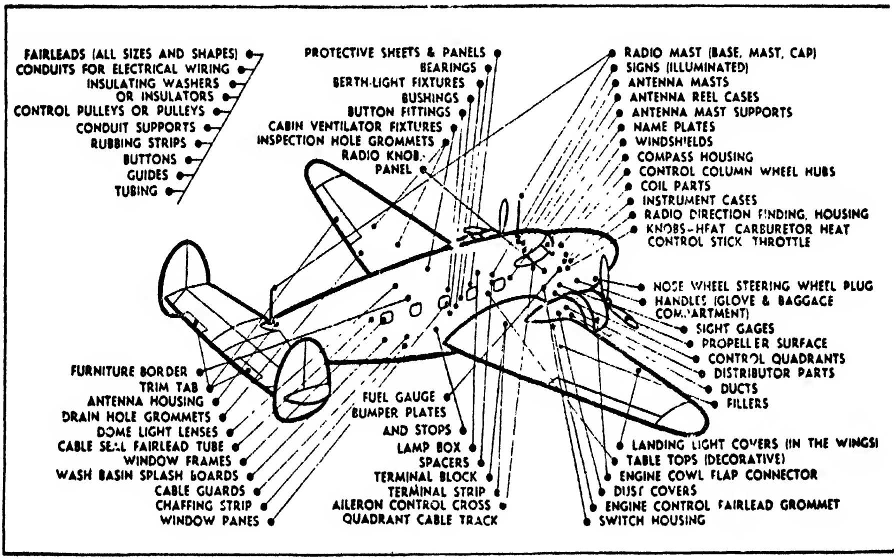


Fig. 72.—Plastic parts on modern aircraft.

Limitations of Each Type of Material

The limitations of the various types of material from the physical properties standpoint have been adequately covered in the foregoing discussion of the various factors affecting design, but the engineer must also have some knowledge of their limitations from a fabricating or manufacturing standpoint, for if such knowledge is lacking there is always the danger of designing a part that is not capable of being manufactured in existing equipment.

Limitations of Thermosetting Materials.—In the case of the laminated thermosetting materials, existing press equipment limits the maximum sizes of flat sheets to approximately 3½ feet by 5½ feet, although a few specific manufacturers may have presses that will handle slightly larger sizes. In the case of the formed laminated parts, such as shallow pans and door panels, the maximum sizes are somewhat smaller in order to provide adequate strength in the special dies used in manufacturing this class of product. Usually, formed laminated parts should not be larger than 3 feet by 4 feet if the parts are to come within the capabilities of a majority of the manufacturers. The minimum thickness in which the materials can be fabricated depends largely on the materials used in the laminations. With the heavier weights of fabric, normally known as " C " grade materials, it is inadvisable to use thicknesses less than $\frac{1}{16}$ inch, as thinner gauges do not have a sufficient number of laminations to provide uniformity in physical characteristics. If a part is to be made thinner than $\frac{1}{16}$ inch, it is advisable to use lightweight fabric, normally known as " L " grade, in order to avoid the afore-

mentioned difficulty. It is possible to make paper base laminated materials in almost any thickness, but its lower impact strength makes it inadvisable to use this grade of material in thicknesses less than $\frac{1}{16}$ inch, as the thinner gauges are too subject to accidental damage in handling and service.

In designing parts to be made from high-impact thermosetting materials, the designer should avoid the use of sections thinner than $\frac{5}{32}$ inch, even in relatively simple parts, and this minimum should be increased for more complex parts in order to prevent distortion and provide uniformity in physical characteristics. If too thin sections are used, it is difficult to made the high-impact materials flow sufficiently to fill the mould completely, and, even if the mould does fill, there are apt to be large variations in the physical properties due to the resin running ahead of the filler. The lower-impact materials will mould satisfactorily in thinner sections down to as low as $\frac{5}{64}$ inch thickness, but designers should be extremely cautious when using these materials because of their low impact strength, particularly in thin sections. In general, the low impact thermosetting materials are not advocated for aircraft use, except in a few special instances, such as instrument cases and knobs, where the danger of accidental impact is slight. They should not be used in structural applications because their impact resistance is materially lowered when they are under stress.

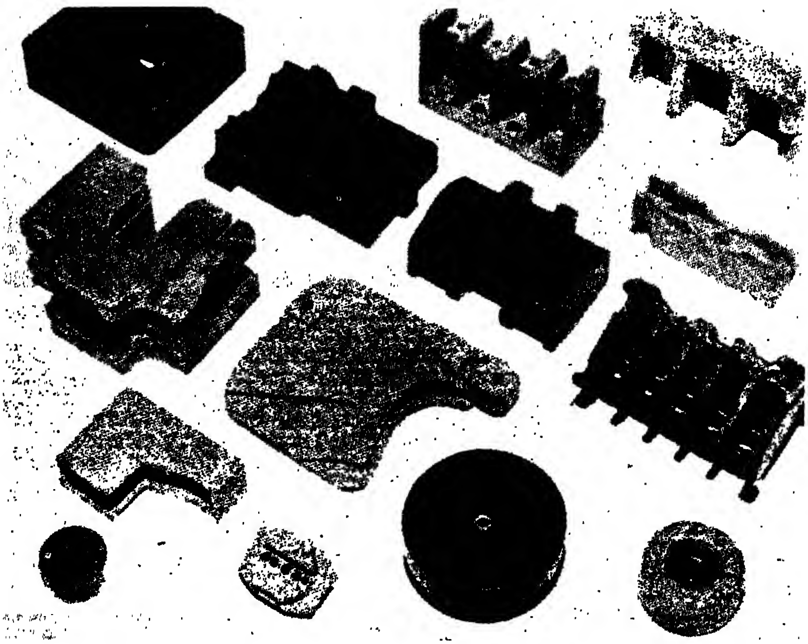


Fig. 73.—Plastic electrical parts.

Parts moulded from either the high- or low-impact thermosetting materials should not generally have a projected area greater than 200 sq. inches, or a maximum dimension greater than 20 inches, for the presses that will accommodate sizes bigger than this are limited in number. The majority of the thermosetting moulders use various sizes of press equipment up to approximately 600 tons and 2 feet square platens, which means that in producing a part having 200 sq. inches of projected area they must use pressures less than 3 tons per sq. inch, even in the 600-ton presses. Considering that it is often advisable to use pressures as high as 5 tons per sq. inch, the designer can readily realise the necessity of keeping the sizes of moulded plastic parts well within the limitations mentioned, particularly when it is remembered that a majority of the press equipment is of even smaller capacities. In utilising the high-impact thermosetting moulding materials, it should be borne in mind that these materials

do not readily flow during the moulding process, and that it is therefore difficult to produce a piece having deep flanges parallel to the moulding direction, since such flanges must be filled entirely by flow of material. If such design details cannot be avoided, it is best to make such sections as thick as possible, so that the resistance to flow will be reduced to a minimum. When inserts are incorporated in such parts they should be designed so that they can be adequately supported in the mould to avoid the danger of their being distorted or displaced by the severe flow conditions. When severe flow conditions exist they can be materially reduced by the use of the transfer moulding process rather than the compression moulding process. The transfer moulding process differs from the compression moulding process in that the material is heated under pressure and reduced to maximum flow conditions in a separate chamber and is then squirted into the mould cavity where the cure is completed, whereas in the compression moulding process the entire action takes place in the mould cavity and therefore creates far greater abrasion and flowing stresses in the cavity than exist in the transfer process.

Limitations of Thermoplastic Resin Materials

The transparent thermoplastic sheet stock is generally made in sheets 20 inches by 50 inches, although in the case of the transparent acrylics, Plexiglas and Lucite, these sizes have been recently increased to approximately 50 inches by 60 inches. When designing transparent parts these basic sheet sizes should be kept in mind, and parts should be so designed that they can be formed from flat sheets of the foregoing sizes. If larger transparent assemblies are to be made, it is necessary to design them so that they can be formed in several pieces and then assembled. This assembly can be accomplished either by the use of metal frames or by cementing the various formed sheets together, using plastic stiffening members at the joints.

A majority of the moulded thermoplastic parts is manufactured by the injection moulding process, although the compression moulding process is used to some degree. Injection moulding machines are rated by their ounce capacity, which indicates the maximum weight of the part they are capable of handling. Only a few of the moulders have machines of capacities greater than 12 ozs., and a majority of the machines in operation are of still smaller capacities. Therefore in designing parts to be injection moulded from thermoplastic materials, the engineer should be careful not to exceed the capacities of the generally available equipment. The injection moulding process permits the incorporation of much more delicate inserts than can possibly be moulded by the compression moulding process, particularly in the thermosetting materials. Compression moulding of the thermoplastic materials is only used where the size of the piece is such that it cannot be handled by the injection moulding machines or where the quantities involved are so small that it would not be economic to set up an injection machine for such a short run. Most injection machines operate on a 15 to 30 second moulding cycle, and therefore they are only used where large quantities are involved. The size limitations for compression moulding of the thermoplastics are approximately the same as the size limitations for compression moulding of the thermosetting materials. Parts that are designed to be moulded from the thermoplastic materials should have sections at least $\frac{1}{16}$ inch thick, but heavier sections are advisable if the part is intricate or if it is subject to low temperature impact. The size of the parts that are to be injection moulded must be designed within the space limitations of the equipment on which the moulding is to take place, and it is best in such instances for the designer to contact several possible moulders and determine what sizes can be handled on their equipment.

Limitations of Wood Veneer Materials

The limitations of the flat, laminated, unimpregnated wood veneer materials—in other words, normal plywood and laminated wood—are well known and need no further comment. The limitations on formed shapes of unimpregnated wood veneer materials depend on the process used and on the equipment available Where such formed shapes are made in hot platen presses, the maximum size limitations are usually somewhat smaller than for normal plywood sheets because of the space taken up by the forming dies. Where formed shapes are made by one of the bag-moulding processes, the size limitations depend on the dimensions of the autoclave or boiler in which the part is cured under heat and pressure. There are several autoclaves in operation of approximately 6 feet to 8 feet diameter by 20 feet in length, and some of the companies are considering installing autoclaves as large as 10 feet diameter by 40 feet in length. The bag-moulding processes therefore place little or no limitation on the size of parts,

and since the pressures used in these processes are relatively low, being approximately 40 lbs. to 100 lbs. per sq. inch, wood dies may be used in many cases, particularly where small quantities are involved, without danger of distortion. Where large quantities and accurate interchangeability are required, it is best to use metal dies, but these are not necessarily expensive. In the bag-moulding process the die and the part are both in the autoclave and therefore the die is not subjected to pressure stresses such as it would be if it formed part of the surface of the pressure chamber. The die can in most cases be made as a skeleton die from sheet metal.

Wood veneer materials of any thickness from $\frac{1}{32}$ inch upwards can be made by either process, but in applications in which there is danger of accidental impact, such as the exterior surfaces of an aeroplane, it is advisable to use material at least $\frac{3}{32}$ inch thick. Internal parts, such as wing rib webs, may be made from thinner materials, since they are not subject to the accidental handling loads which may be imposed on exterior surfaces. When wood veneer materials are used to form part of the exterior surfaces, it is preferable to use at least five plies in their construction in order to reduce the possibilities of surface checking and fracture of the protecting finish. Three-ply plywood construction always produces a sheet that is notably stiffer in one direction

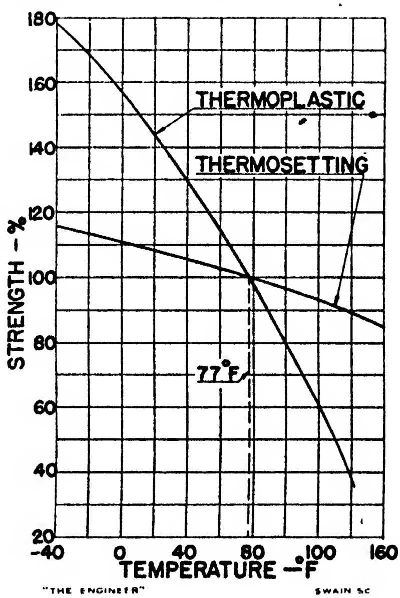


Fig. 73a.—Chart of temperature and strength of plastics.

than the other, and this difference tends to produce cracking or checking of the surface plies under vibratory conditions, particularly where fluctuating atmospheric conditions also exist. This difference may be greatly reduced by increasing the number of plies, resulting in a sheet having a more uniform stiffness and greater ability to withstand the effects of vibration and weather. In the fabrication of such laminated wood veneer materials it is also advisable to use relatively thin face plies, as these are less subject to surface checking than thick ones.

Since the unimpregnated wood veneer materials must be adequately protected from the weather, it is essential that the finishes be so applied that all surfaces are completely covered. In order to accomplish this result it is often necessary to use a mask when finishing parts that are subsequently to be glued, and where such masks are used they should be so designed that only a minimum amount of material is left unprotected in the final assembly. This means that the mask not only must be of the same width as the glue area it protects, but also the assembly must be accurately indexed so that the masked area corresponds exactly with the joint being glued. In many instances, applying the finish by dipping will avoid the use of masks, but when this is done the

designer must be careful to provide adequate access and drainage for the finish, otherwise there will either be unfinished areas or large amounts of finish trapped in the structure. In designing assemblies to be made from wood and wood veneer materials, end-grain gluing should be avoided, for such joints cannot be relied upon to carry stresses and yet are expensive to manufacture, since the parts must be made to such close fits in order to accomplish this type of joint. In almost all cases this type of joint can be avoided by the use of glue blocks that can be manufactured as standard parts and readily installed. In order to avoid the possibility of the workman attempting to make such end-grain joints, it is preferable to show a $\frac{1}{16}$ inch clearance on the drawing, so that the parts will be definitely scant and the joints made entirely of the glue blocks. Finish should be applied to such end grain prior to assembly in all cases where it is not definitely certain that complete coverage will be obtained in final finishing.

The impregnated wood veneer materials of high density, approximately 1.4, have to date only been moulded by the hot press method, and therefore the sizes available in this material are limited to the platen sizes of the hot plate presses used, er approximately a maximum size of 4 feet by 8 feet. If formed parts are mane frsm this material, the sizes will be somewhat reduced because of the space taken up by the die. The impregnated wood veneer materials of low density (approximately 0.6) may be processed in either of two ways :—(1) The veneers may be impregnated, coated with adhesive, assembled to form the laminated material, and cured and bonded in one operation in a hot press ; (2) the veneers may be impregnated and cured, after which they may be assembled and bonded, using normal hot or cold-setting resin adhesives. If the first process is used, the materials can only be advantageously manufactured by the hot press method, but if the second process is used the impregnated cured veneers can be handled in a bag-moulding process in the same fashion that the impregnated veneers are handled. Therefore this process can be used to manufacture parts of either unimpregnated veneers or of low density impregnated veneers. The use of impregnated cured low density veneers in the bag-moulding process will eliminate many of the objections to unimpregnated wood construction from the standpoint of moisture absorption, as previously discussed.

Tolerances

The laminated thermosetting materials can be machined to approximately the same tolerances that are used at present for metal parts, except that ground finishes cannot be produced to the same accuracy as is possible with metal. The tolerances needed in the manufacture of thermosetting and thermoplastic parts depend on the complexity of the part and on its physical dimensions. In general, a tolerance of $\pm$ 0.0025 inch per inch of dimension is satisfactory for dimensions that are entirely controlled by one part of the mould. If, however, a dimension is controlled by more than one part of the mould, an additional tolerance of $\pm$ 0.005 inch should be allowed for each mould joint line. If a dimension extends across a flash line—that is, between plunger and mould—an additional tolerance of $\pm$ 0.010 inch should be allowed. The above tolerances are for general moulding practice, and can in special instances be reduced to as little as 40% of the above values, but with attendant increase in die cost and rejection. Although shrinkage allowance is made in designing the mould, the foregoing tolerances are necessary in order to take care of variability between different batches of material and minor variations in moulding temperature and pressure.

In manufacturing large parts, such as pilot's enclosures, from formed transparent sheet stock, the tolerances must be wider, in order to accommodate the existing methods of manufacture. In general, a tolerance of $\pm \frac{1}{8}$ inch should be allowed on contours and on all dimensions, except those that may be controlled by drill jigs or like fixtures. Closer tolerances may be used in local regions on such structures, but these generally require special machining operations after the part has been fabricated.

In parts manufactured from the wood veneer materials, the normal tolerances at present used in sheet metal construction will generally apply, except that the gauge of laminated wood veneer materials may vary through wider limits than are normally present in aluminium alloy sheet stock. Formed sheets of laminated wood veneer materials up to $\frac{1}{64}$ inch thick can be controlled in thickness within tolerances of $\pm \frac{3}{16}$ inch, but when the thickness approaches $\frac{1}{8}$ inch it is best to increase the tolerance to $\pm \frac{1}{32}$ inch, although closer tolerances are possible by special selection of veneer. In designing matching parts in wood veneer construction, allowance should always be made for the thickness of the finish as well as for the general tolerances, otherwise the addition of the finish may make assembly difficult.

Applicable Specifications

The Army and Navy have issued material specifications covering laminated phenolic sheet, tube, and bar for electrical uses, moulded phenolic materials for electrical uses, transparent thermoplastic sheet, and resin-bonded aircraft plywood of the unimpregnated type, but Government specifications are not available for structural thermosetting moulded materials, for structural thermosetting laminated materials, for structural thermoplastics, or for impregnated wood veneer materials. Government specifications have been issued to cover adhesives and finishes in certain specific classes of materials, but additional specifications are necessary before this field is adequately covered.

The most urgent need at the present time is for specifications covering the structural plastic materials, particularly the moulded thermosetting plastics. If the existing specifications on electrical materials are used for structural parts, they are unduly restrictive in that the part must then be controlled for electrical properties, which entails sacrifice in the physical properties. In order to obtain the maximum electrical properties in thermosetting plastics a high resin content is required, and this reduces the mechanical strength, particularly the tension and impact strengths, materially below the values that might otherwise be attained if the resin content were adjusted for maximum strength. The Air Corps and Bureau of Aeronautics are at present co-operating on a programme to develop such structural plastic specifications, but until the new specifications are issued the aircraft manufacturers must resort to use

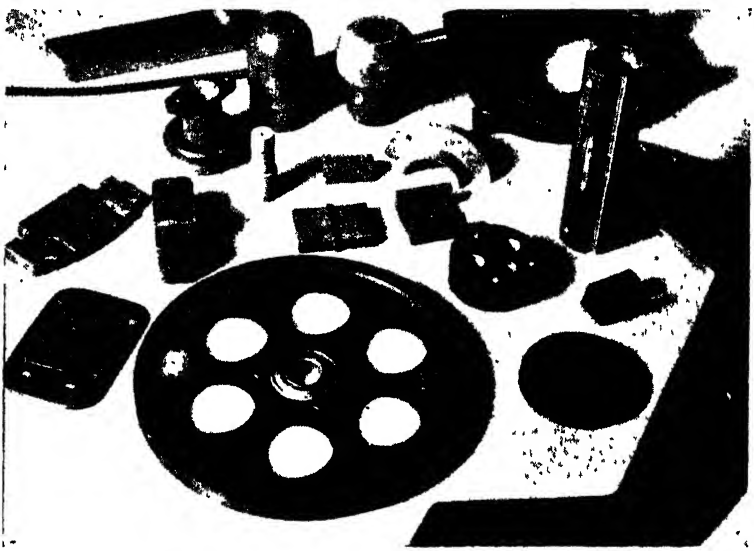


Fig. 74.—Aircraft components in Bakelite laminated.

of the specifications of the various raw material suppliers. Most of the raw material suppliers have technical data books in which they list the complete mechanical and electrical properties for each of the materials they produce. From inspection of these technical data books the aircraft manufacturer can select a group of materials which fulfils his needs. The aircraft manufacturer can then set up his own procurement specifications until such time as the Army and Navy issue specifications controlling the structural materials.

Availability

In determining the availability of plastics and allied materials from an aircraft standpoint, not only the raw materials but also press equipment and tools and dies must be considered. Since aircraft receive top priority on plastic raw materials, and since the total volume produced exceeds by many times any possible aircraft demands, there should be no difficulty in readily obtaining adequate supplies of raw materials.

As the plastic moulders and laminators have always had sufficient press equipment to absorb the entire production of the raw material suppliers, there should be ample capacity to take care of all aircraft needs. In the moulded plywood industry, particularly where the bag-moulding process is used, there is a possibility that a shortage of moulding equipment will exist if the entire aircraft industry attempts to take full advantage of moulded plywood products, but, since the equipment consists mainly of simple pressure boilers, it should not be difficult to expand the facilities in time to meet increased aircraft demands.

The development of adequate facilities for the production of tools and dies in which to manufacture the plastic parts is one of the main problems before the plastic moulders and laminators at the present time. Only a few of the plastic laminators and moulders are equipped to produce 100% of their die requirements in their own plants, by far the greatest majority relying on outside machine shops for all or part of their die requirements. These tool and die facilities were adequate for peacetime operation when manufacturers were doing a large volume production of relatively few parts, but, when it is considered that aircraft require a relatively small production of a large volume of parts, it can be readily realised that the demand for tools and dies will be greatly increased and that plastic manufacturers should therefore make every effort to increase their tool facilities to meet the changing conditions. If this is not done the aircraft industry will be restrained from taking full advantage of these materials.

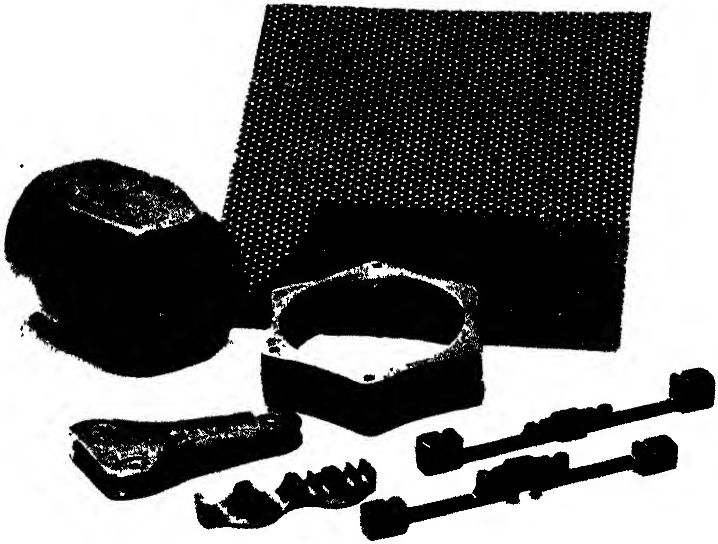


Fig. 75.—Another batch of Bakelite aircraft components.

Possible Savings of Aluminium

The extensive utilisation of plastics and allied materials will also be of appreciable aid in relieving the current aluminium situation.

(1) If the aircraft industry would utilise the thermosetting plastics where practicable in secondary structural and non-structural applications, it would be possible to save up to 20,000,000 lbs. of aluminium per year without jeopardising the safety of the aeroplanes by attempting to use the material in highly stressed parts or questionable applications.

(2) If the aircraft industry would utilise thermoplastic materials for all transparent enclosures and for other suitable internal parts, it would be possible to use approximately

10,000,000 lbs. per year, of which up to 1,000,000 lbs. might be assumed to replace aluminium alloy support frames and miscellaneous parts.

(3) If the aircraft industry would utilise the wood veneer materials for such sub-assemblies as bomb bay doors, wheel well doors, bulkhead doors, removable wing tips, table tops, cabinets, and miscellaneous equipment items, it would be possible to save up to 20,000,000 lbs. of aluminium per year without attempting to extend the use of wood veneer materials to such items as fixed tail surfaces, wing outer panels, or fuselages.

This means that a total of 41,000,000 lbs. of aluminium per year could be economically saved by the use of plastics and allied materials in applications in which they are equally suitable, and in which they do not affect the overall design of the aeroplanes upon which they are used. In other words, the utilisation of plastics and allied materials would save in one year approximately six times as much aluminium as was collected throughout the entire country in the recent aluminium drive.

(The above article is based, of course, on American data, though naturally most of its conclusions apply equally to British conditions.)

PLASTIC REPLACEMENT OF METAL PARTS

THE application of moulded plastics to aircraft can be grouped into three categories; firstly, true replacements where the synthetic product is superior in all respects to the material it replaces; secondly, alternatives where plastic materials are equal to the original from a production and Service viewpoint; and thirdly, substitutes where the plastic material is not so suitable, but it materially conserves other material which is in short supply.

At present moulded plastics have a definite wartime value as substitutes for metals; it is not difficult to find metal fittings built up of several items, each involving in the process of fabrication a high percentage of waste material. These items are assembled by bolting, screwing, or welding and the finished fitting is finally protected by painting or plating, and in some cases by both.

Fig. 76.—Self-aligning bearing, with Bakelite core.

In all probability the same object could be achieved by moulding in phenol-formaldehyde powder at one operation, the subsequent work being merely de-flashing and light buffing where necessary.

For structural and other lightly stressed parts phenol-formaldehyde or urea-formaldehyde resins are used; these are strengthened by the addition of fillers—cotton linters, threads, silk, etc. Some typical examples of mouldings are illustrated on the accompanying photograph.

Figure 77 shows, at the left, the upper and lower halves of a fuel cock housing. This complete assembly is pressure tested to 40 lbs. per sq. inch. The component was previously manufactured from machined magnesium alloy castings. Owing to a

certain amount of porosity, plus numerous machine operations it was obviously more economical to produce as a plastic moulding which had none of the disadvantages of the original design.

At the top of the same illustration there are three control knobs, previously fabricated from light alloy; and below them two trim tab handwheels, previously machined from light alloy castings. The machining of these details was expensive, as it will be noted that an involute groove is machined on one face. When produced as a plastic moulding, the subsequent operations merely consisted of removing flash and buffing one face, thereby considerably assisting production.

The small self-aligning bearing is illustrated in more detail in Fig. 76. The bearing is an interesting development and was evolved to replace the more normal type of self-aligning ball bearing. The design consists of three parts, the outer race machined from steel, the centre piece of steel tube, and the core is a Bakelite type filled powder. Adhesion of the core to the centre piece is achieved by knurling the outside diameter of the tube; the inner diameter of the outer race is spherically round, which ensures a high degree of finish with resultant good alignment and rotational properties. The plastic core is moulded *in situ*; the subsequent work merely consists of removing flash. This $\frac{5}{16}$ inch bore self-aligning plastic bearing is used in flying controls and hinges of control surfaces in training type aircraft.

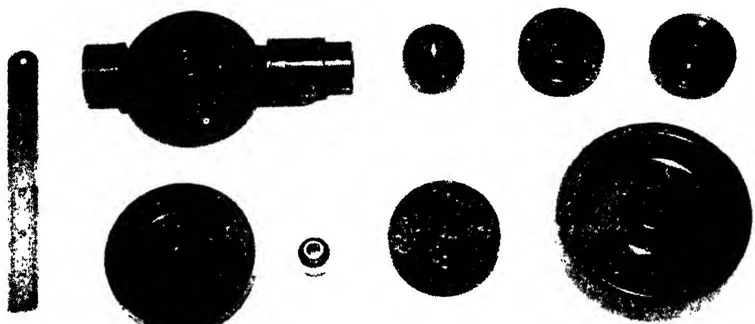


Fig. 77.—Phillips and Powis mouldings, replacing metal parts.

The resultant finish of plastic mouldings is far superior to that normally obtained from metal and it should be noted that this objective is attained with no burden on production. The plastic article is completely non-corrosive, nor does it generate a potential difference when mated with dissimilar material. It has particular advantages when used in proximity to the crew of an aircraft: there are no sharp edges or corners to injure maintenance or flying personnel.

The development and use of moulded plastic articles in aircraft must follow the expansion of the aircraft industry, there can be no sudden growth; it is highly probable that the phenol-formaldehyde resins will establish themselves as the active ingredient of moulding powders of the Bakelite type. Their future most probably lies in the direction of small mouldings of approximately 16 ounces in weight.

AIRCRAFT PLYWOOD

DESIGN requirements of early aircraft brought about the first real exploration of the strength/weight ratio of plywood, when it was used for monocoque fuselage construction and for sheathing the leading edges of the wings. It was discovered to have many virtues as an aircraft material: non-splitting, easy to cut, easy to curve and to form, it was inexpensive, could be obtained in quantity, and it had unusual dimensional stability, to mention a few. In its existing form, in the World War and immediate post-war days, it had failings, too. The "weakest link" in the chain of plywood construction was the bonding agents, casein and albumin glues. Early aircraft builders also considered plywood too inflammable.

In spite of its limitations plywood was used for aircraft for some years after the war, then toward the late 'twenties it was gradually replaced by metal.

In the early 'thirties resin adhesives of the plastic industry attracted the plywood manufacturers. They tried phenol formaldehyde film and found it far more durable than casein or albumin as a hot-press adhesive. It gave a completely water-proof product, one well-nigh immune to bacterial growth, and since it was boil-proof it could be bent and curved easily after steaming. The aircraft industry became interested again. Subsequent development of liquid phenolics by the plastic industry proved of even greater assistance in plywood progress.

Bonding with Resin Film

Bonding plywood with film is simpler than mixing and spreading liquid, though both methods are used. Interleaving the dimensioned dry film between veneers of 8 to 12% moisture content is the only preparatory step required. With liquid adhesive mixing, spreading and pre-drying consume time. Assembled sheets of veneers and adhesives are heated and pressed for from 5 to 12 minutes at 300° F., depending on the thickness, and a pressure from 125 to 250 lb. per sq. inch, varying with the density of the wood. Resin adhesive technique requires more care and precision than the older glues.

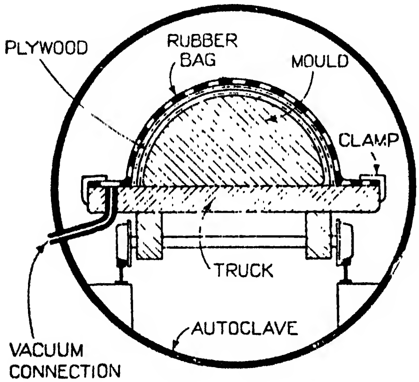


Fig. 78.—The Vidal system of plywood moulding.

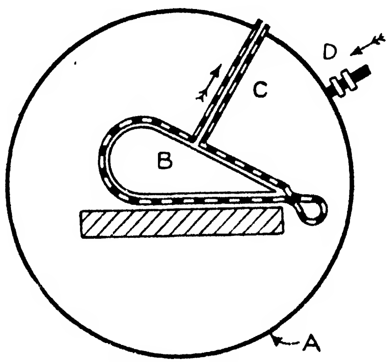


Fig. 79.—Forming plywood units over a male mould.
A. *Pressure tank or autoclave.*
B. *Sub-assembly in rubber bag.*
C. *Vacuum or air connection.*
D. *Connection for steam pressures.*

The effect of the thickness of the veneer layer on strength characteristics of plywood shows some interesting trends. Improvement is negligible between $\frac{1}{8}$ inch and $\frac{1}{16}$ inch veneer, but conspicuous from $\frac{1}{16}$ inch to $\frac{1}{48}$ inch. It is possible that $\frac{1}{32}$ inch veneer would give excellent strength values, comparatively, but this has yet to be confirmed.

While the above procedure applies to plywood made flat, it is equally practical to form (during bonding) a wide variety of plywood shapes in pairs of heated metal dies. Where there is likelihood of the shape rupturing the veneer, reinforcing layers of fabrics are inserted. Flat plywood, within reasonable limits, can be steamed thoroughly and formed and dried in wood or metal dies, using heat where speed is required. Wood rupture in acute curvature can often be avoided by placing veneer layers at 30 or 45° to the axis of curvature. A wide range of constructions is available to meet various needs.

An early difficulty in aircraft plywood was the gummed tape used to hold laminations together edge to edge. The narrow ribbons of paper weakened the plywood joint when they delaminated. Edge gluing equipment for veneer has now become available, in the form of heat reactive resins. The resulting edge joint is as strong as the veneer. The processes described above apply to normal plywood where the density of the wood may be somewhat increased by addition of resin and the slight compression of the veneers required to bring the surfaces into intimate contact for bonding

High Density Plywood

Further, compression imparts an entirely new range of strength properties, using veneer sheets of around $\frac{1}{48}$ inch thickness, with alternative layers cross-laid, and resulting in almost complete impregnation of the resin adhesive into the wood. A distinctly lower rate of progress, however, is to be found above 1,000 lb. pressure. It required 105 sheets $\frac{1}{48}$ inch poplar to produce a 1 inch thick sample at 1,500 lb. pressure. This high-density plywood can also be made by applying liquid phenolic resin, pre-drying and then hot pressing as in the case of the dry film. While considerably more complicated, this process gives more complete impregnation. In general, the use of film results in wood reinforced with resin, with wood characteristics predominating. Use of liquid resin produces a plastic reinforced with wood.

When soaked this high-density plywood tends to expand part way back towards its original thickness, but to a lesser degree than normal plywood. This improvement in plywood strength, through increase of density, is comparable with alloying and heat treatment of metals. It gives wood-workers an opportunity to meet design requirements far beyond the range of normal plywood. Experimental work on high-density plywoods is proceeding rapidly. The most durable plywood, from all viewpoints, is that made with phenol formaldehyde resin adhesives. Adequate machinery has been developed to manufacture flat and moderately curved plywood economically.

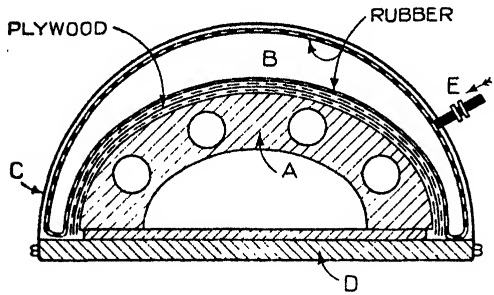


Fig. 80.—The earlier Duramold process in which an inflated rubber bag was employed.
A. *Cast-iron mould.*
B. *Rubber bag.*
C. *Steel shell to retain bag.*
D. *Baseplate.*
E. *Pressure connection.*

Assembly Problems

The major adhesive problem now facing the aircraft manufacturer, in so far as making plywood-plastic planes is concerned, is the many manual operations of putting the laminations together preparatory to bonding under heat and pressure. Here a suitable adhesive is admittedly superior to nails; screws and bolts and casein had been found the best glue until the early 'thirties. Its limitations have been increasingly evident in the last year or so with plywood again being used in the aircraft industry. Casein, though as strong as the wood when dry, and water resistant, delaminates after limited soaking in cold water and very quickly in hot water. It is abrasive for cutting tools and poorly resists bacterial growths.

Phenolic resins appear to be the answer, but have not yet found general favour in assembly work as their low heat reaction is definitely inadequate. Fortunately another group of resins, the urea-formaldehyde type, are well adapted to assembly purposes. The adhesive mixtures " live " for four hours after mixing, with a proper catalyst, and cure at room temperatures of 70° F., although the quality of the bond improves and cure accelerates under heat up to 140° F., while under pressure for a four- to eight-hour period. These adhesives come in liquid form, and in powder form, with catalyst incorporated. It is often advisable to use a small amount of relatively inert extender as a " body-maker " to reduce the absorption into the more porous species of wood. Pressures for this type of cold setting resin need only be enough to bring wood surfaces into intimate contact, or slightly to compress such a soft wood as spruce.

Urea resins, with a cold setting catalyst, are benefited by temperatures up to 130–140° F., therefore, and one way to accomplish this is to store jigs, clamps and assemblies in an air-conditioned chamber for the required period. Drying of the wood members must be guarded against in air-conditioning, for they should retain their normal moisture. Wet and dry bulb thermometer reading tables should be obtained for this purpose, and the air-conditioned chamber controlled accordingly.

Moulding Aircraft Units

"Plastic planes" is a somewhat inaccurate description. Planes so far made and described as such have been moulded plywood with resin adhesives and finishes. Plywood moulding principles are old, and the only new features recently introduced by "plastics" plane makers were the methods of applying the pressure, and the unusually large size of the moulded unit. The fundamental principle is the use of an inflatable rubber bag as one of the halves of a pair of moulding dies. It saves the costly matching up of a pair of dies where the intermediate distance between halves must be very accurately determined. The duramold, Timm and Vidal plywood-plastics processes utilise rubber bags.

An early type was the vacuum bag, used with cold-setting glues for the facing of wood core pilasters with veneers. The wood cores are accurately machined and very thin veneers used. After the adhesive is applied the parts are assembled and inserted in the bag where pressure is reduced to a vacuum. While this pressure cannot exceed 15 lb., the manual pressing of the veneers against the cores will help to smooth out the curves. Quick-setting glues hasten this operation.

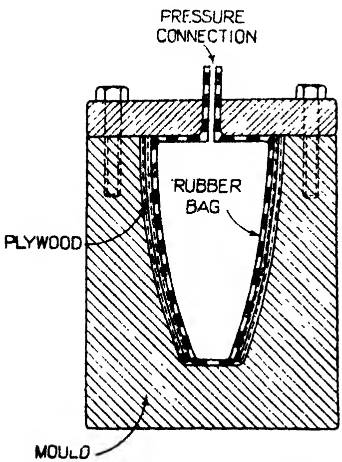


Fig. 81.—*Internal moulding process of Merron, Ltd.*

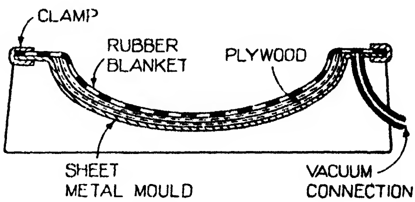


Fig. 82.—*Later Duramold process employing a female sheet-metal mould, in conjunction with a rubber blanket.*

A method now used to mould half fuselages consists of inner and outer dies of metal or wood. The outer shell must be of sheet metal, substantially cylindrical in shape, and firmly bolted to the base plate on which the inner mould rests. This may be of metal or of framed wood fitted with inlet pipes for the admission of pressure and having slots to accommodate the frames, longerons or stringers. The wood parts to be moulded may be of veneer or plywood, but must be cut to such tapers that each layer covers the preceding one completely and without laps. These parts must be held in approximate locations by tacks, paper or cloth tape, steel bands or wire. A deflated rubber bag is placed over the freshly spread wood layers, and the outer sheet is dropped over the hole and bolted to the base. The rubber bag is then inflated with air, hot water or steam, and the wood layers are pressed and bonded together as well as to bracing frame members inserted in the mould. This method has also been successful for making the plywood hulls of small boats.

In the method of moulding by internal bag pressure, pressure is applied inside the sub-assembly and forces the plywood against an outer mould which may be of metal, steam-heated, or of wood. A heavy cap is bolted over the pressure inlet end of the die.

Aircraft sub-assemblies can be moulded together by placing them in a rubber bag and placing the bag in a pressure tank, equipped with a vent to atmosphere, and filled with steam at 50 to 100 lb. pressure. This method is used to mould sub-assemblies such as wings, ailerons and tail surfaces, where plywood skin covering is bonded direct to skeleton wood framework.

Standardised Design Necessary

There are many other possible combinations. The chief obstacle to broader use of this rubber bag method of plastics-plywood construction is lack of standardisation in aircraft design. The excellent strength-weight ratios of plywood and the smooth exteriors, without rivets, both add to the air effectiveness of such types of planes.

The conventional method for manufacturing aircraft plywood with synthetic resin adhesives has been the use of the steam-heated platen in a hydraulic press. While entirely satisfactory on thin plywood, a definite limit in thickness appeared when time of heat penetration became excessive, and the temperature gradient required to polymerise the resin in the central layers caused an over-drying of the outside layers.

This problem is being solved by the use of high-frequency electrostatic fields. The material to be heated is placed between the electrodes, and experience shows that suitable temperatures for resin cures can be obtained very quickly, even in the centre of a block several inches thick. As a matter of fact, the temperatures attained by the wood are less than those that occur in the adhesive material. This process shortens the bonding time to such an extent that the wood layers suffer little loss of moisture content.

Fig. 83.—Building up the plywood skin of a half-fuselage on a wooden mould, and stapling it in position. The supporting structural members in their slot locations are shown.

There are fundamental differences in design requirements between wood and metal in aircraft construction. Wood has bulk and stiffness with high strength-weight ratios. Wood surfaces can be glued together. These facts give substance to the belief that moulded plywood parts, with light, but strong, arch effects, will be important factors in the aircraft of the future.

Plywood Spars

Another important use of aircraft plywood is in laminated parts. The term laminated refers to the parallel grains of the adjacent layers, while regular plywood has alternately crossed grains. A solid piece of wood, of same size and species, is less desirable for

aircraft than a laminated piece of the same dimensions, since the fabrication permits balancing or bracing grain effects, reinforcement of adjacent layers, freedom from checking and more uniform moisture content. While spars for small "cub" planes are often solid wood, there is a distinct tendency to make them of laminated layers. In general these spars are approximately 1 inch by 6 inches at the large end, tapered toward the small end, and in solid lumber seldom are available over 20 feet long. If laminated from ⅛ inch spruce, the lengths can be increased to almost any desired point by staggering and scarfing the splices With a properly applied resin adhesive the quality of the laminate will be superior to solid spruce and the cost not out of line.

In larger types of trainer planes spars may either be made of overlaid ⅛ inch layers of solid wood or by aggregating pieces of laminated construction. These large spars

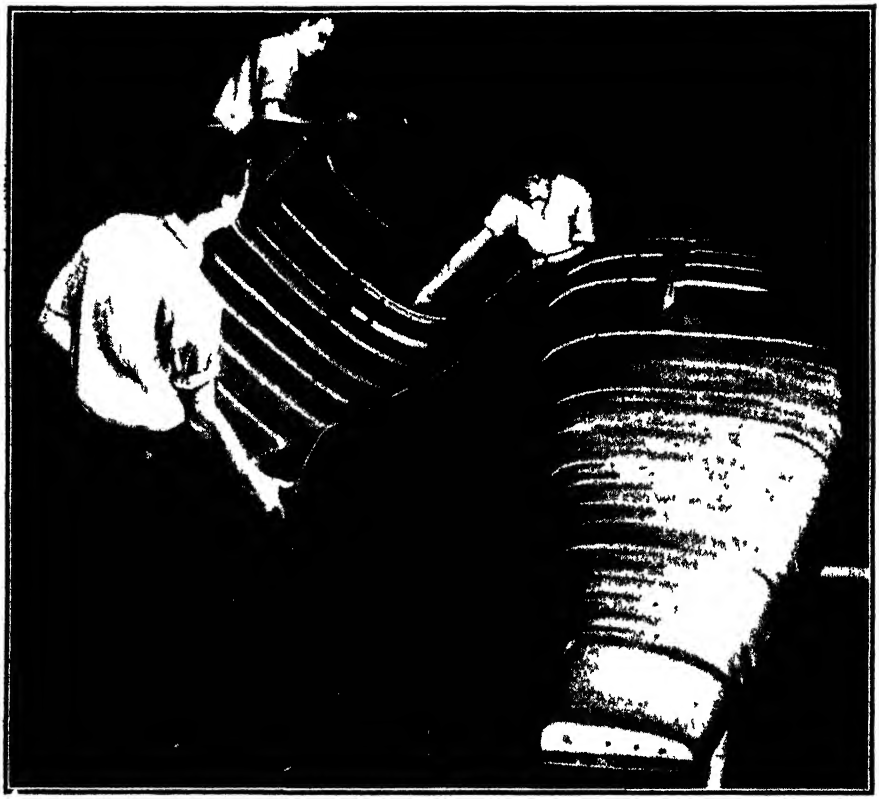


Fig. 84.—Removing a half-fuselage section of the Langley aircraft from the mould after forming. The internal framework is bonded to the skin, in the mould.

are often built up to 3 inch or 4 inch thickness at the fuselage ends, for reinforcing, while the layers taper or leaf-out toward the outer ends. Some spars are made of hollow beam construction toward the outer end, with thin diagonal plywood covering. Urea resin adhesives are suitable for all spar joints, while phenolic resins are preferable in the plywood used for covering.

Ribs and Gussets

There is a wide range of construction and designs possible in wooden ribs and gussets. It should be kept in mind that, under column types of loading, solid wood often has a favourable strength-weight ratio over plywood, while for distributed strength

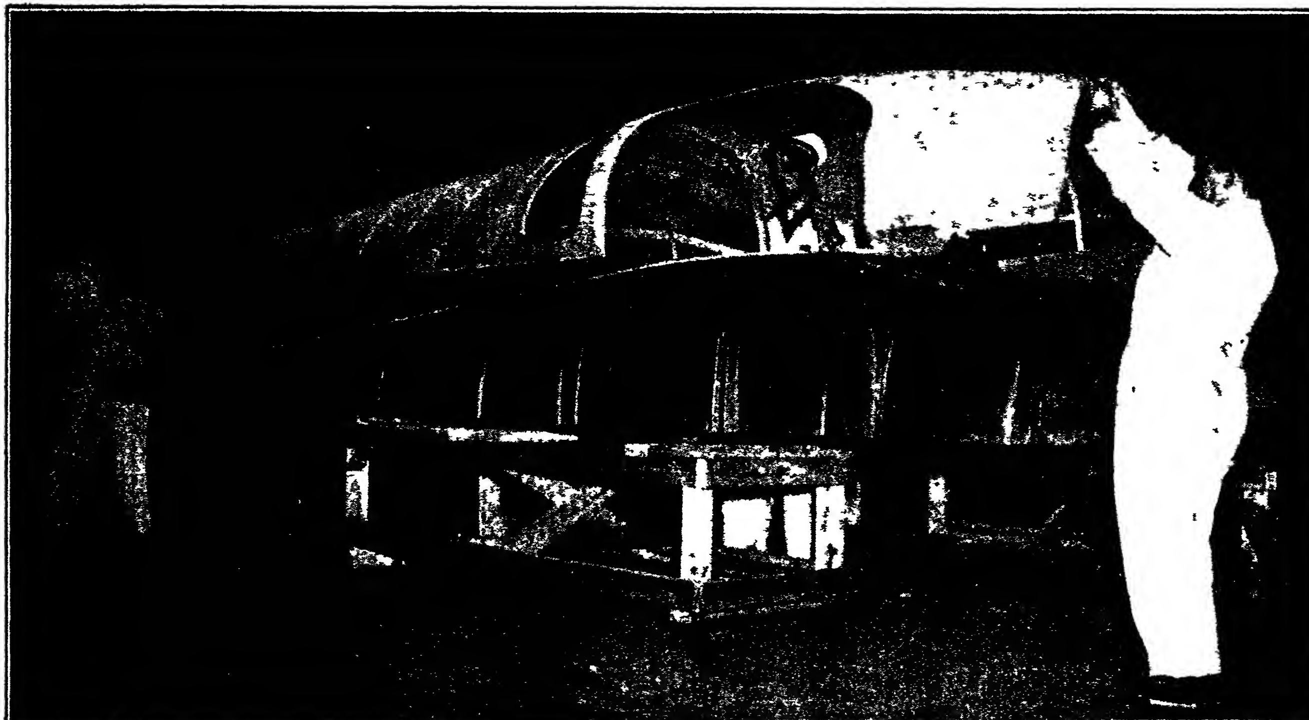


Fig. 85.—A completed port half-fuselage after withdrawal from the pressure chamber, being removed from the mould. Skin and supporting structure are bonded into an integral unit.

and non-splitting qualities plywood is far superior to solid wood. As in the case of the spar constructions, urea resins are best for assembly joints, while phenolic resins are best for joints in the plywood. In the case of such small areas as are involved in sub-assemblies, sufficient pressure is often obtainable by properly designed nails, with or without nailing strips, and sometimes by strong spring clamps. The important point is to bring surfaces into intimate contact.

Plywood as Skin Covering

One of the fundamental advantages of plywood is its stiffness-weight factor. For example, aluminium sheets have a specific gravity of 2.8 approximately, while spruce plywood has a corresponding characteristic of 0.5 to 0.6. Hence for an equal weight plywood can be four to five times as thick, or for equal thickness plywood is correspondingly lighter. Plywood can be glued to the ribs and spars, while metals have to be riveted, a distinct disadvantage. The springiness of wood renders it less easily damaged and, if damaged, it is simpler to repair.

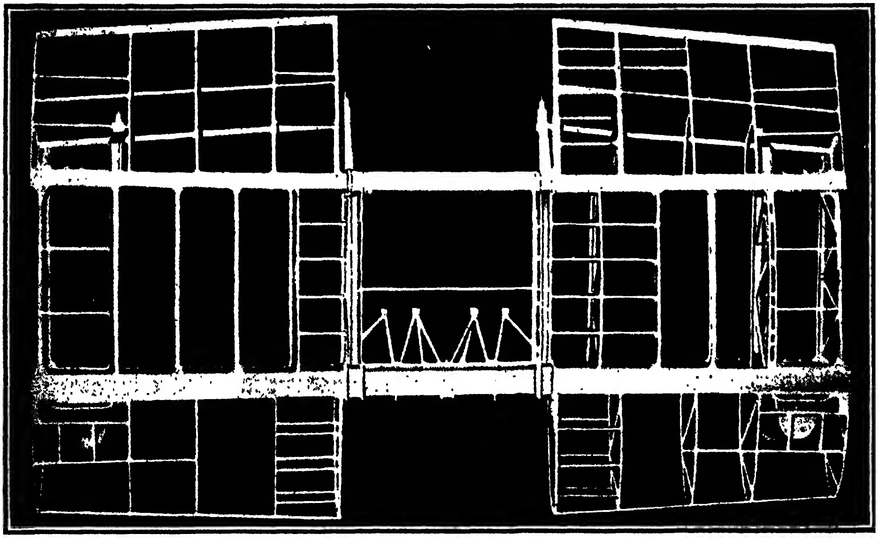


Fig. 86.—The centre section spars of Fairchild P.T.19 are of phenolic resin bonded spruce laminations—a special application of the Duramold process.

Certain combinations of plywood thickness and curvature can be bent cold and dry. If the curve is too severe, bonded plywood can be softened by steaming and then bent and dried over either a single or double form which may be heated. Sometimes rather sharp curves are facilitated by bending at 45° with the face of the plywood, rather than parallel to any layer within the plywood. It is becoming increasingly apparent that thicker skin coverings, at such locations as leading edges, may permit the elimination of a substantial number of ribs, with reduction in time, weight and cost. In some cases these thicker plywood surfaces may consist of several layers of two-ply bonded together with rubber bag pressure.

Solid lumber, such as the spruce used in spars, splits easily and has low bolt-holding power. Hence spruce spars require sturdy reinforcement where attached to fuselage or landing gear. While metal plates are often used it is possible to get excellent results with reinforcing plates of high-density plywood. The resistance to shear is increased some sevenfold, as between solid wood and plywood pressed at 1,000 or 1,500 lb. specific pressure. While both solid maple and normal pressed plywood (200 lb. per sq. inch) are used, the denser product offers distinct advantages in the weight-shear ratio, i.e., where shear resistance increases some 700%, the specific gravity or weight increases only 114%.

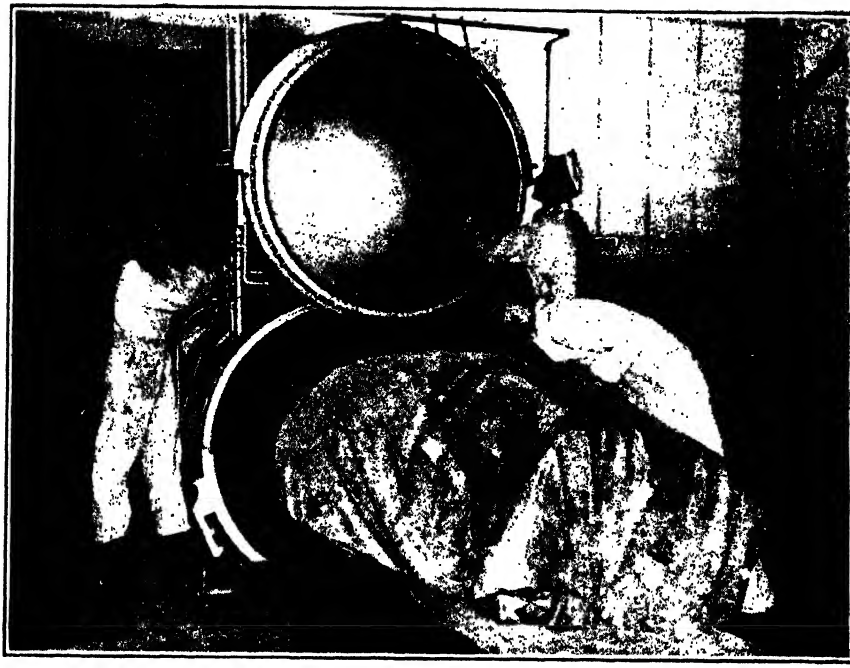


Fig. 87.—Pushing the half-fuselage prepared for moulding and encased in its rubber bag into the pressure chamber.

Fig. 88.—One of the first moulded aircraft units to be produced in the United States : the Clark fuselage made by the Duramold process.

One important factor in using high density plywood for reinforcing plates is to have the surface, adjacent to the soft wood, sufficiently roughened so that the bond will be both mechanical and adhesive. A simple way to accomplish this is to have one surface of the high density plywood pressed (as it is made) against a knurled plate, or even against a properly proportioned metal screen, so that the resulting ridges and valleys are from $\frac{1}{32}$ inch to $\frac{1}{16}$ inch high and not farther than $\frac{1}{8}$ inch apart. Such a roughened surface can be pressed into the spruce by the bolts, and will result in a mechanical grip of unusual strength.

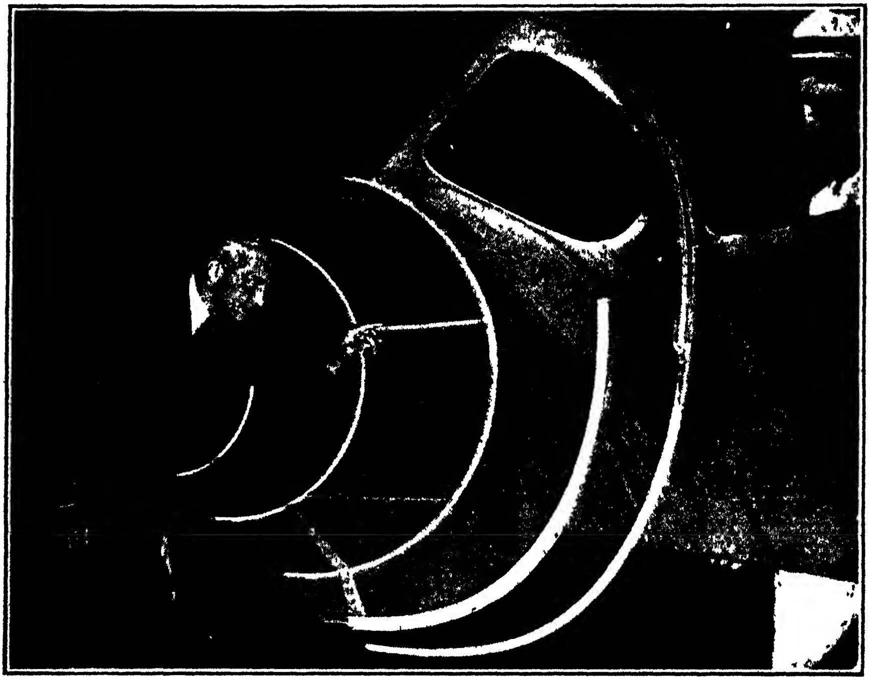


Fig. 89.—A half-fuselage section being examined. The lightness of the supporting structure is noticeable.

Plywood, while depending for its strength characteristics on the strength elements of various sheets of veneer, still presents several new and valuable qualities. In addition, there are many principles of design and types of construction in plywood that can be used to secure special strength requirements. It is for this reason that plywood offers unusual advantages to the aircraft engineer.

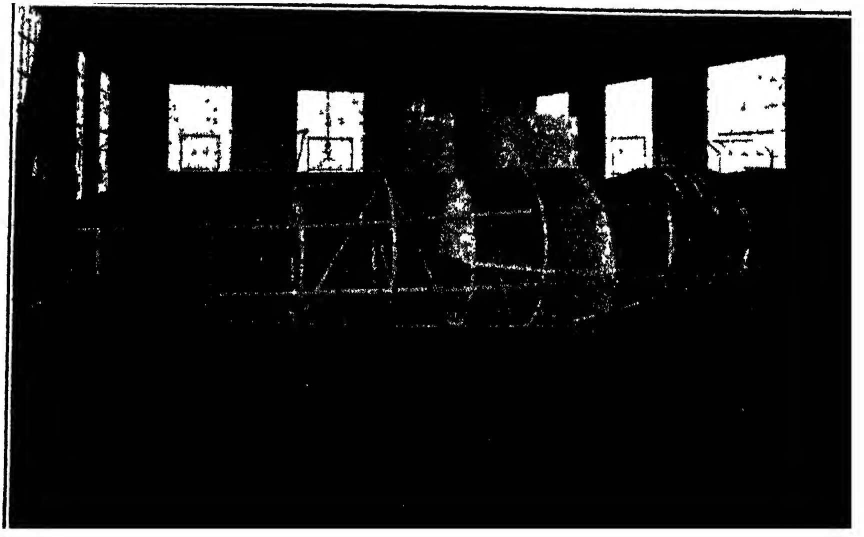


Fig. 90.—The Timm structural framework in a separate jig. The whole assembly is bonded in a separate curing operation.

Fig. 91.—Building up the veneers for the Timm fuselage.

GLUEING DEVICES

GLUES of animal and vegetable origin normally in use in the aircraft industry are tending to become superseded by the use of synthetic glues, the inherent qualities of which can be utilised to decrease their natural drying or hardening time at normal temperatures—of approximately four to five hours—to time which is only 12% of this—in some instances even less, dependent largely upon the thickness of the ply or wood laminations being glued.

It is in the exploitation of the qualities of the glue by varying methods of heat application that the resourcefulness of one firm has found scope.

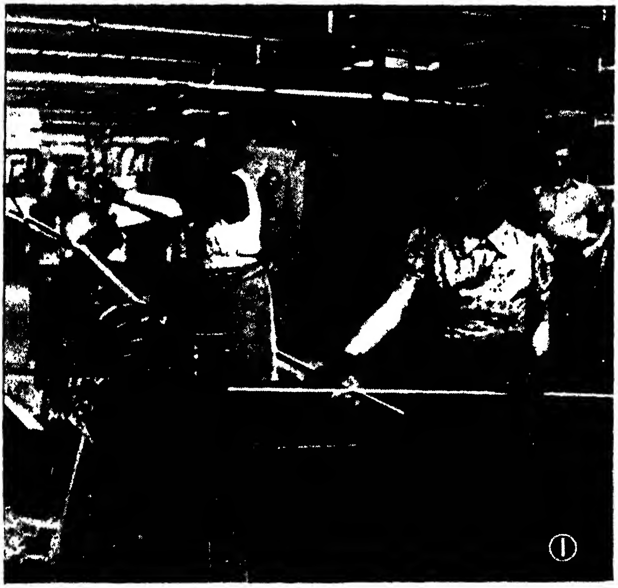


Fig. 92.—Laminæ are glued on the roller machine.

The accompanying illustrations show some of their devices in operation, but by reason of limited space they are confined to one small feature of the production on which the firm is engaged.

An Electrically-heated Bending Jig

Figs. 92 and 93 show the application of the glue by different means, whilst Fig. 96 shows a bending-jig in which heat is applied by electricity.

Along the inner member of the bending-jig depicted, a loose metal strip is placed, over which the glued laminæ is laid. Also on the top of the laminæ and under the pressure blocks another similar strip is placed.

Pressure is applied by the blocks and wedges shown, and then the strips are electrically heated to approximately 90° C.

It will be seen that this electrical heating can be applied to an infinite variety of component parts and to many different types of jig.

When bends are being glued, it is generally found advisable to allow time for cooling, amounting approximately to the equivalent of the heating time. In the articles under consideration, for example, the total production time was forty minutes, approximately half of which was taken up in cooling.

The use of synthetic glues has proved extremely successful and they have been much preferred, although it has been agreed that their application entails careful technique, with strict control of mixing and the period of use. Once, however, experience of

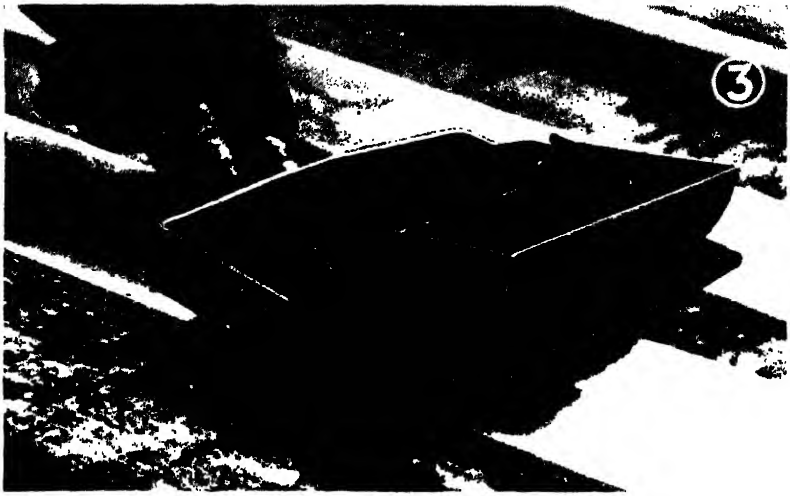


Fig. 93.—A hand-operated roller for applying glue to shaped laminæ which cannot be glued in a machine.

Fig. 94.—Outside ply skins are glued to these fuselage frames in the press shown in Fig. 95.

the glue has been gained, no trouble need be anticipated. The glues, when set, are impervious to changes of temperature and unaffected by water. Recently the various firms producing such glues have evolved "gap" glues, in which it is claimed, and the firm whose methods are being described has proved, that an effective joint has been obtained even when a slight gap up to approximately 0.020 inch- has been left between the two surfaces being joined.

Hand Roller

Application of glue in the ordinary way results in a good deal of mess and consequent unnecessary waste. The factory visited was notable, however, for the absence of both these objectionable features.

Roller machines apply the glue to the laminæ at speed, the glue being fed from a trough against the rollers. For curved parts which cannot be put through a machine, the small hand-roller has been evolved. This is also fitted with a trough to distribute the cement. It is a simple tool which admirably serves its purpose—an example of the application of practical common-sense. The idea seems so obvious that one

Fig. 95.—A steam-heated press in which fuselage frames are glued to skin.

would expect to find it at any hardware store. However, it has been made by the firm for their own use, and its advantages are demonstrated by the requests the management have received for replicas.

Other methods of producing and applying heat can, of course, be used. Fig. 95 shows a large steam-heated platen press which is used to glue the two outside ply skins of the fuselage frame held by the girl operator in Fig. 94. This operation is completed in the comparatively short time of approximately eight minutes.

It is hoped at some future date to deal with some of the other practical devices the firm has in use, such as stencil masks for use on air-frame ply skins, a system of barrel construction of fuselages, revolving doping fixtures, and a method of internal dope-spraying which eliminates traffic to and from exterior dope-shops.

The reduction of a four-or-five-hour process to a few minutes, by means within easy reach, is a matter that should commend itself to the notice of every woodworking firm in the country.

Method of Use

A FEATURE of the past year has been the steady incursion of synthetic resin adhesives, largely of the urea-formaldehyde type, into wooden aircraft construction. Till recently casein glues held the field because, notwithstanding their technical disadvantages, operators were familiar with their use and characteristics. The introduction of gap-filling synthetic adhesives, and the realisation of the enormous increase in speed of production as well as the improved resistance to moulds and to water obtainable have, however, completely changed the picture. Aero Research, Limited, of Duxford, Cambridge, who were the pioneers in the introduction of such adhesives, have produced Aerolite 300F with Hardeners GBP and GBQ for aircraft use. Aerolite 300F is a liquid urea-formaldehyde product which is applied to one of the surfaces to be joined while the hardener (either GBP or GBQ, depending upon the speed of set desired) is applied to the other. The two surfaces while still damp are then clamped together

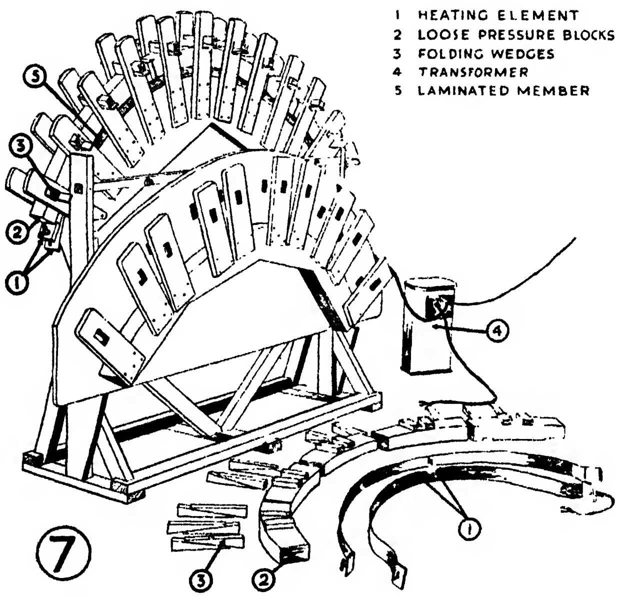


Fig. 96.—A bending jig in which heat is applied by electricity to a laminated bend, " glued " with synthetic adhesive.

for 1¾ hours at a temperature of 70° F. (21° C.) or if GBP is used for two hours at the same temperature. Aerolite 300F and these hardeners are officially approved for aircraft use. The raw materials are produced in this country and are not in short supply.

Setting Time

Although even at room temperature the use of Aerolite 300F with hardeners GBP and GBQ give a much quicker setting-time than casein, an even greater speed can be attained by the use of a technique devised some time ago by Aero Research Limited (see *British Plastics*, August, 1936) and now being widely adopted by the aircraft industry. The principle involved is illustrated in the accompanying figure, which shows the construction of a curved laminated wing tip bend from spruce laminations glued together with Aerolite glue. The type of jig is a familiar one but it differs from normal practice in the insertion of a thin steel strip against the outer faces of the

laminated bend. The two free ends of this strip are connected to a step-down transformer (such as is used in spot-welding) and by passing a current through the strip it is instantly brought to a temperature of about 212° F. (100° C.).

This rise in temperature produces an enormous increase in the speed of setting which becomes a matter of a few minutes only. Due to the low voltage employed there is no danger from electric shock.

Another advantage in technique due to Aero Research, Limited, is the manufacture of aircraft plywood meeting B.S. Specification 5V3 by the use of a foam process.

Plywood is made of one of two specifications, D.T.D.427 or B.S.S. 5V.3 requiring resistance to three hours' immersion in water at 60° C. (140° F.) and 100° C. (212° F.) respectively. At present urea-formaldehyde resins are used for D.T.D.427 plywood, and Tego film (paper dry state) for the 5V.3 plywood. On the whole the phenol-formaldehyde resins are more water resistant than the urea-formaldehyde resins (though the latter can be given sufficient water resistance to meet the three hours' boiling test of specification B.S.S. 5V.3 by the use of certain modifying agents) but they need higher pressures and temperatures to set them than do the urea-formaldehyde resins.

Use with Thin Veneers

Although modified urea-formaldehyde glues meet the requirements of B.S.S.5V.3 they cannot be used in the manufacture of very thin plywood because of the swelling caused in the thin veneers by the wet glue and because of the penetration that takes place after subsequent pressing. The phenol formaldehyde film type of glue is of course immune from these troubles.

To meet this difficulty and at the same time to reduce costs, Aero Research, Limited, have introduced a foamed modified urea-formaldehyde glue which in many respects combines the advantages of liquid and of film glues with the added advantage of low cost.

The idea behind this process is that provided penetration of the glue into the veneers is obviated, only a very thin film of glue is needed to make good joints, and the amount of glue applied by any ordinary means (glue spreaders or brushes) is in excess of the optimum amount. By using the glue in the form of a foam of about the same consistency as the lather produced from shaving soap, an extremely uniform spread is obtained in terms of pounds of glue per sq. foot.

Actually the volume of the glue is about doubled by a special beater machine before it is poured into the glue spreader. Under ordinary factory conditions, without taking any special precautions, it is possible to get a spread of 1.35 lbs. of glue per 100 sq. feet.

This foamed-up Aerolite Glue gives plywood meeting the requirements of specification 5V.3. Because of the nature of the foam it can be used with thin veneers without producing excessive wrinkling or causing overlaps in the cores. The foam is allowed to dry on the veneers after it has come through the rollers of the glue spreader. It does this very quickly and in fact the film of foam will be found to be dry by the time the veneers have been assembled for pressing.

The press temperature required is 90° C. so that steam-heated presses are unnecessary and the older type of press so common in this country with hot-water heating can be used. The use of the pressing temperatures below 100° C. obviates any risk of over heating of the wood with its attendant troubles.

From a national point of view this ingenious process is of some importance because it enables two important materials—urea and formaldehyde—to go twice as far as before.

RUBBER IN THE MODERN AEROPLANE

RUBBER and synthetic rubber are used in a variety of forms and compositions in aircraft of to-day; these forms include sheet, tubing, moulded parts, sponge, hard cellular forms, and hard rubber blocks.

The first rubber that meets the eyes of the layman is probably the tyres on the landing wheels. In the early days shock cord was used for cushioning the landing shock, and for a variety of other purposes, such as bungees on controls, seat adjustments, suspension for radio apparatus and instruments.

The original usage for landing shock absorption was to wrap numerous strands of shock cord about each end of a straight wheel axle and undercarriage strut, the weight of the aircraft determining the number of strands to be used. A later method consisted of forming rings or loops of shock cord and stretching these rings over pins in stationary and movable telescoping members carrying the wheel and the axle. This method was used by Fokker on tri-motored transports.

For the benefit of those who are not familiar with the term shock cord, it is made in various diameters ranging from ¼ inch to 1 inch. It is constructed of numerous strands of live rubber pre-stretched and then enclosed in a woven fabric casing in such a manner that it can be extended up to 300% of its free length. In the case of the rings or loops the strands of rubber are lapped, and a continuous outer woven casing is applied.

Tyres and Tubes

The aircraft tyre differs considerably from the automobile tyre. Aircraft tyres are generally made with a smooth tread and are of streamline cross-section ; the edge above the bead blends with the wheel rim so as to form a smooth flat side between the tyre and the wheels. This is done to reduce drag or wind resistance during flight. Most of the modern airplanes are designed so that the wheels are retracted into the structure during flight and only the flat side of the tyre and wheel is exposed to the airflow. Landing gears are usually designed to stand a drop test of the completely loaded airplane for a vertical distance of four feet. This test is conducted with the tyres and wheels in place.

De-Icers

Ice forming on the wings causes loss of lift and eventually will cause a forced landing or wreckage of the airplane. De-icers consist essentially of a hollow rubber covering fastened along the leading edge of the wing cellule, with sectional compartments built in and connected by tubing to a distributing valve. These compartments are alternately inflated and deflated by an air pump forcing air through a rotary distributing valve. The action of inflating and deflating these compartments or cells causes the ice to crack and break away from the wing surface.

Engine Mountings

In the early days of aviation, engines were usually mounted directly on wooden bearers and bolted solidly. This method was acceptable when engine powers were low, but as powers increased, a means of isolating engine vibration was sought.

A design in which the torsional movement of the engine is absorbed by rubber in shear, and the thrust taken by rubber in compression, is now used in the majority of high-power engine installations. By proper design of the rubber, which is bonded to an inner and outer cylindrical sleeve, or by building the pad into a sandwich type of mounting, the torsional resonant frequency can be controlled to predetermined values, and resonant frequencies in other modes of vibration may be placed out of the cruising speed range. Also, we can reduce transmission to the aircraft structure of vibration impulses resulting from exciting forces inherent in the power plant, produced by firing order and unbalance couples of propeller and engine combination, as well as various types of motion which are subject to resonant vibration as excited by the power plant.

The first rubber bushings used in compression were designed for a natural torsional response frequency of as low as 1,200 cycles per minute by varying the hardness, placing holes of various sizes through the rubber to allow flow, and by varying the thickness.

The shear-type bushings were designed for lower torsional frequencies of 600 cycles per minute ; this was possible owing to the softness of the shear type of support. However, we cannot make it too rigid because of possible yawing or pitching on account of high-frequency resonant response to the exciting couples of forces applied away from the mounting bushings, or too soft on account of drooping of the engine assembly in the mounting. This, then, is the reason for using a combination shear and compression type of rubber mounting.

Rubber used in these mountings must be of the best grade, as it is usually exposed to heat within the engine compartment in addition to the heat generated within the rubber owing to the frequency of vibration. It is also subject to oil fumes and oil spray. Synthetic rubbers have been tried and found lacking in rapid recovery, and

they also tend to take more of a permanent set under load than rubber. The design of rubber mountings is very important in order that the spring rate and loading per sq. inch is correct for the particular engine, propeller, and plane combination.

Instrument Mounting

In order to protect valuable and delicate instruments from destructive vibration, the entire instrument panel is usually mounted on shock absorbers similar to, but smaller than, the engine mounting types. Here again we use rubber in shear to isolate vibration.

Sealing Rings and Packings for Hydraulic and Oleo Struts

Rubber sealing rings or packings of C or chevron type are used in the hydraulic cylinders for operating landing gears, flaps, etc., and also in the oleo struts on the landing gear to absorb the shock of landing. These struts are similar to the shock absorber struts used on the modern automobile, but operate under much higher load condition and pressures. As these struts are under pressure when the aircraft is standing on its wheels, the slightest leakage permits the struts to collapse. Therefore extreme accuracy for these rings and the material used therein is important.

Miscellaneous Seals

A great many seals of all types, sheet, tube, and moulded parts of rubber, are used to close openings where air leakage may occur. Sometimes these seals must withstand high temperatures and are often exposed to spilled gasoline or oil, in which instances synthetic rubbers are utilised.

Cowling Supports

Engine cowling, whether it be for in-line or radial type engines, is subject to vibration and expansion due to the movement of the engine mounted in vibration isolators and to the heat developed by the engine. Usually some part of the cowl is mounted or supported on the engine and because of the moment arm the amplitude of movement is greater than that of the engine. It can readily be seen that without some means of dampening the oscillations of this cowl, it would probably shake itself to pieces or at least break loose from the airplane.

The method of supporting the engine cowl is similar to that of supporting the engine. A number of shear-type rubber bushings are utilised to isolate and dampen this vibration.

Cowling is generally built in sections to expedite removal and to provide access to the engine compartment. Because of the flexibility of the structure, these sections would chafe at the joints and in time rub through if they were not protected in some manner. No great clearances or gaps can be left between the sections; so we resort to rubber chafing strips to prevent rapid wear on the cowling sections.

Flexible Ducts

Flexible ducts made from rubber and fabric and sometimes of moulded synthetic rubber are used to conduct air, both hot and cold, to various parts of the airplane for carburettor air, cockpit ventilation and heating, and gun warming.

Connecting Sleeves

Because of relative movement between various parts of the airplane we must eliminate chafing between these parts and yet retain tight joints. Such parts as air intake for carburettors, superchargers, oil cooler and radiator air ducts, all require some form of flexible connecting sleeves or joints. These sleeves are often subjected to pressures of two or three atmospheres and are made of moulded and reinforced rubber, or synthetic rubber where heat and oil vapours are encountered.

Fuel, Oil and Coolant Connections

For the same reasons as given above, the fuel, oil, and coolant lines must also be flexibly connected. A synthetic rubber and fabric hose which will not be affected by gasoline, hot oil, or hot coolant (usually ethylene glycol) has been developed to form these connections. In the case of the oil system these connections must also withstand pressure up to 200 lbs. per sq. inch. These connections are slipped over the end of the tubes and special connections at the tanks, radiators and engines, and are fastened by means of hose clamps.

Electrical Insulation

Although rubber is used for electrical insulation throughout the airplane, the most important application is in the high-tension ignition system. All high-voltage conductors carry the current along the surface. This tends to produce corona which breaks down the insulation by creating ozone which is a super-oxygen and the enemy of rubber. Moisture is also an enemy of rubber insulation and is produced by condensation and pressure changes. With increasing altitude the difficulty of insulating these high-frequency currents increases as the density of the air changes with altitude.

In an effort to protect the rubber insulation from oil vapours and moisture rot, a coating of synthetic rubber over the rubber was tried but later was abandoned. Now we use a coating of tough lacquer which resists the moisture rot and is proof against corona.

Tank Support

A good grade of gum rubber is used for lining the fuel tank and oil tank cradles and the supporting straps so as to isolate vibration and shocks encountered during landing and take-off. If we did not cushion these metal tanks they would soon leak, as they are very light and often carry as much as 200 gallons in one tank.

Fuel Tank Protection

A new use for rubber and synthetics has been developed during the present war in the form of bullet-proof fuel and oil tanks. An inner bag of a synthetic which must prevent gasoline from permeating the bag or absorbing any residue from the bag is deliberately covered with a pure latex rubber which is readily attacked by gasoline and will swell and become sticky immediately upon contact with the gasoline; outside of this is an outer covering of synthetic rubber and fabric or leather to give strength to the cell. All fittings and connections are moulded of a synthetic rubber which has good resistance to swelling and is not attacked by immersion in gasoline. In American practice, the entire cell is inserted in a metal container. When a bullet penetrates the tank it pierces the inner ply, and the gasoline attacks the latex rubber, causing it to swell and seal the wound. This must occur rapidly because a leak would constitute a serious fire hazard as well as cause the loss of fuel needed to get back to the airplane base. British bullet-proof tanks are covered by such sealing on the outside.

Radio Suspension

Radio transmitting and receiving sets, being sensitive to shock, are mounted in various types of shock absorbing supports, utilising rubber in various forms. Sometimes use is made of shear-type soft rubber mountings similar to instrument mountings, and at other times sponge rubber or shock cord is used.

Shock Cord

Shock cord is still used extensively for balancing controls and as a means of counterbalancing seats, flexible machine guns, etc.

Radiator Mountings

Radiators, and oil coolers are also protected from shock and vibration by the application of rubber in various forms.

Hand Grips

Various hand grips and knobs, which may be either of hard or soft rubber, are used on controls throughout the airplane.

Walkways

Rubber is used for cabin floor covering and walkways on the wings to prevent slipping and the scuffing of the wings.

Battery Containers

Airplane storage batteries follow the trend of automobile batteries and are built with hard rubber cases and use rubber plate separators; spilled acid and gases are carried off by means of rubber tubing.

Grommets and Moulded Parts

Wherever a line, conduit, or control passes through a bulkhead, a grommet is used to prevent chafing and to seal any air leakage. Throughout the airplane moulded

rubber or synthetic rubber parts are installed to act as scuppers around tank filler caps, to protect parts from dirt or from becoming jammed owing to foreign objects falling into them. A very interesting method of using rubber bellows as seals around control rods, to allow movement and at the same time stop any flame from passing through the bulkhead to the pilot, is now practised.

Line Supports and Clamps

All fuel, oil, coolant, hydraulic, air, etc., lines must be supported at intervals, against our two enemies, vibration and chafing. These supports must be so rigid as to cause line breakage from movement ; so we again resort to rubber to cushion these supports. A metal clip is made with a moulded rubber liner inside, which is wrapped around the line or tube and fastened with a screw or bolt to the structure. Where multiple tubes are carried parallel to each other, rubber blocks split in half with openings for the tubes are utilised.

Flotation Bags

Land planes to fly over water are equipped with flotation bags constructed of balloon fabric and collapsed into a compartment inside each wing. A door over the compartment is equipped with a spring latch or release to allow the bag to eject from the wing when inflated. The bags must be light in weight, readily packed into small space, and of such size that when filled with gas, their displacement equals the weight of the aircraft. They are attached to the undersurface of the wing and usually are braced with flexible guy ropes to hold them in position when inflated.

A cylinder of carbon-dioxide gas under high pressure is stowed in the aircraft and connected to these flotation bags by means of tubing. The gas bottle is equipped with a quick release in order that the pilot may liberate the gas from the bottle and inflate the bags through the tubing connections as rapidly as possible when he contacts the water.

Life Rafts or Dinghies

The flotation bags described above do not always save the aircraft, for if the sea is rough and the aircraft is not retrieved by a rescue boat in a short time, the bags may be torn away from the wing or may be punctured. For this emergency the pilot is provided with a collapsible rubber life raft, which may be inflated by a small bottle of carbon-dioxide gas carried for the purpose. The life raft is constructed of rubberised fabric and is equipped with a patching kit, a hand air pump for keeping it inflated, a small paddle, emergency provisions, and a water bottle.

Diaphragms in Carburettors and Fuel Pumps

The rubber diaphragm method of metering fuel to the carburettor and cylinders has now eliminated the old method of admitting the fuel by means of a float valve and has made possible a steady flow of fuel under pressure in any flying position.

Propeller Cuffs

Variable pitch propellers are constructed with removable blades. These blades necessarily require a round section shank where they are locked into the hub, and this round section causes a turbulent condition of air flow near the hub.

Means for increasing the efficiency of this section of the blades have been tried, and by placing streamlined blade section cuffs around the shank of the propeller blades an improvement in performance and also cooling air flow has been obtained. Moulded cuffs of rubber which slip over the blade shanks have been tried and may later be adopted.

Seat Cushions

Seat cushions and backs of sponge rubber have proved practical for airplanes ; the sponge-type cushions are relatively light and comfortable.

Electrical Properties

Rubber is a good electrical insulator. There are times, however, when we desire a surface to be a good electrical conductor in order to carry off surface static charges. One instance is the rubber fuel tank. Here we have a serious hazard with gasoline and static electricity. Some of the synthetic rubbers are fair conductors of surface electricity, and their use is desirable in such a case.

Strength

Strength is not always a design factor, but is desirable. Some synthetic rubbers are lacking in strength as compared to vulcanised natural rubber, and others have a bad tendency to cold flow.

Ageing and Temperature Resistance

Resistance to ageing and extreme temperature ranges is desirable in rubber or synthetic rubbers for aircraft use. Rapid and extreme temperature changes are encountered when an airplane leaves the ground and climbs to high altitudes.

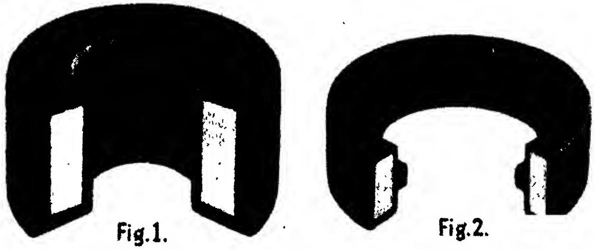


Fig.1. Fig.2.

Fig. 97.—" Relt " rubber mouldings with felt core.

Rubber Mouldings with a Felt Core

" Relt " is the first result to be publicly announced of the intensive research drive carried on ever since the danger of a rubber shortage became imminent.

" Relt " is in effect a new rubber moulding technique wherein the mouldings consist of a core of felt surrounded by a " corral " of rubber. The immediate and obvious advantage of the new process, for which patent applications have been made, is the tremendous savings in raw rubber amounting in many types of mouldings to as much as 75%. There are, however, a number of additional advantages claimed for " Relt " and actual production of the new material which is already under way is leading to the discovery of new features and benefits which were at first unsought and unexpected. Among the more obvious advantages is the fact that " Relt " mouldings are from 30% to 75% lighter in weight than pure rubber mouldings. For instance, a hollow cylindrical moulding (Fig. 97-1) measuring 1¾ inches deep with an outer diameter of 3¼ inches and a bore of 1½ inches was originally moulded in a rubber mixture and weighed 2.56 ounces. The same moulding produced under the "Relt" process has an inner core consisting of two pieces of felt 1½ inches deep by 2¾ inches outside diameter and 1¾ inches bore and in its new form weighs only 1.76 ounces. The saving in weight in this particular case is therefore 32%. Since the raw rubber content of this moulding is now only 0.54 ounce as against the original rubber content of 1.15 ounces, it will be seen that the saving of raw rubber is over 53%. On a production run of 100,000 of these mouldings the rubber saving of nearly 1¾ tons is considered to be a worthwhile result of the research which preceded the perfection of " Relt " process.

A still more outstanding example is a ring-shaped rubber distance piece—(Fig. 97-2) which the Empire Rubber Company previously moulded in rubber in large quantities. Under the " Relt " process this moulding shows a weight reduction from 1.20 ounces to 0.46 ounce, representing a saving of 61% and at the same time the amount of raw rubber in the moulding is reduced by 70% from 0.80 ounce to 0.24 ounce. Here again the rubber saving on a production run of 100,000 mouldings is over 1½ tons.

Another claim made for " Relt " by the joint inventors is that variations in the degree of resilience are more easily secured than with normal rubber mouldings, since the felt core can be provided in a range of different degrees of hardness.

" Relt " also opens up new fields for the production of certain types of components, wherein previously, although the desirable qualities of felt were required, it had been impossible to overcome the absorbent nature of this material. By this special union with rubber, however, felt is now insulated from the effects of damp and the manufacture of a variety of products previously impossible has been facilitated.

ASBESTOS IN AIRCRAFT CONSTRUCTION

ASBESTOS is a fibrous non-metallic mineral with properties which make it uniquely suitable for a number of diversified uses in aircraft construction. It can be spun into yarn and woven into cloth, and since it is non-inflammable and fire-resistant, it can be used on aircraft in situations in which no other kind of textile material could be employed. Asbestos felt, enclosed in a covering of asbestos cloth, is used as an insulation for hot air ducts and fuel tanks, and asbestos yarn is used for covering exhaust pipes. Asbestos millboard is used for fireproof bulkheads, and asbestos webbing is used to provide a relatively soft seating at joints between sheet metal sections. Asbestos fibre, bonded with rubber, is the foundation of compressed asbestos fibre sheet jointing material, out of which are made gaskets for cylinder heads, pipe flanges in cooling systems, etc. Asbestos fibre is also used as a reinforcing and filling material for plastic mouldings and sheet materials suitable for constructional purposes. The principal manufacturers of asbestos products make it part of their business to assist firms contemplating the specialised employment of asbestos.

AIRCRAFT APPLICATIONS OF GENERAL PROCESSES AND PLANT

SOME of the processes, machine tool and otherwise, which are applied to modern aircraft, have been described in their application to a particular type—stretch pressing on Spitfire, rolling and drawing on Wellington, and flanging on Blenheim. Reference should be made to these subjects in the Index.

But there remain tools and processes which can be applied to aircraft production, though not necessarily designed specially for that purpose. Turning, milling, drilling, routing, bending, gauging, marking and heat treatment are processes common to all engineering; and it is proposed to deal here only with tools and equipment of types actually being applied to the production of aircraft components.

Airframe spar plant, for example, has been greatly developed recently to meet the need of the airframe industry to produce airframe spars on a large production basis with a minimum labour force.

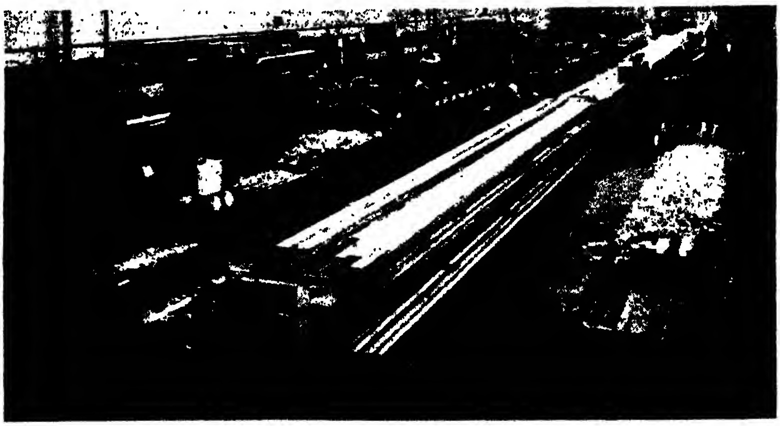


Fig. 98.—Wadkin Spar Miller.

Wadkin Spar Miller

The spar milling machine, for example, is a new type of machine tool which has been specially designed for machine milling aircraft spars at high rates of production. The machine consists of a long fixed worktable and bed and a travelling cutter-carriage fitted to the bed and actuated by rack and pinion. All machines are now fitted with copying attachments for cutting irregular-shaped profiles or tapered spars, often called for on aircraft construction.

The need for high production has led to an increasing use of tungsten carbide tipped cutters and this has resulted in the development of a very heavy machine fitted with spindle drives of 75 h.p. and feed traverses up to two feet per minute for heavy spars; and 50 h.p. and speeds up to six feet per minute for light spars. These increased feeds have reduced the machining time of spars to a matter of minutes, so that the loading time and handling time may be 90% of the floor-to-floor time. To remedy this, hydraulic clamping fixtures have been developed for clamping the spars in the fixture. All the clamps are power operated by switching on the oil pump motor, and a great amount of setting-up and unloading time is saved.

Another important development is the use of a suction exhaust equipment to extract the chips as they are generated at the cutter and deposit them in a container. The exhaust box unit may be mounted on the travelling head as a complete unit, or it may be located at some distance from the machine and a flexible pipe used to convey the chips. This development is important because as much as forty cubic feet of chips may be generated on a pair of spars in thirty minutes' cutting, and their removal after being cut takes a lot of time and labour before the next spars can be mounted in the fixture.

Cutter speeds are still in the development stage, but peripheral speeds of 2,000 feet per minute are now commonplace for carbide cutters, and cutters for speeds up to 5,000 feet are being developed.

Figure 98 shows a Wadkin heavy spar milling machine equipped with a 75 h.p. spindle motor, cutting lightening pockets in two aircraft spars, using two 14 inch diameter milling cutters. The machine is equipped with hydraulic clamping fixtures, and is arranged to cut five pockets of various lengths along the spar. All this milling

Fig. 99.—Wadkin Spar Drill, with radial arm.

is done automatically; the length and depth of each pocket is controlled by electric trips fitted with micrometer adjustment and mounted on the front of the table. The method of operation is as follows:—

Start up spindle, start traverse; the cutterhead moves along the bed until an electric switch on the overarm engages with the first trip in the front of the table; the horizontal traverse then trips out and the vertical down feed commences and goes on until the cam engages the next trip; this cuts out the vertical traverse, and the horizontal feed

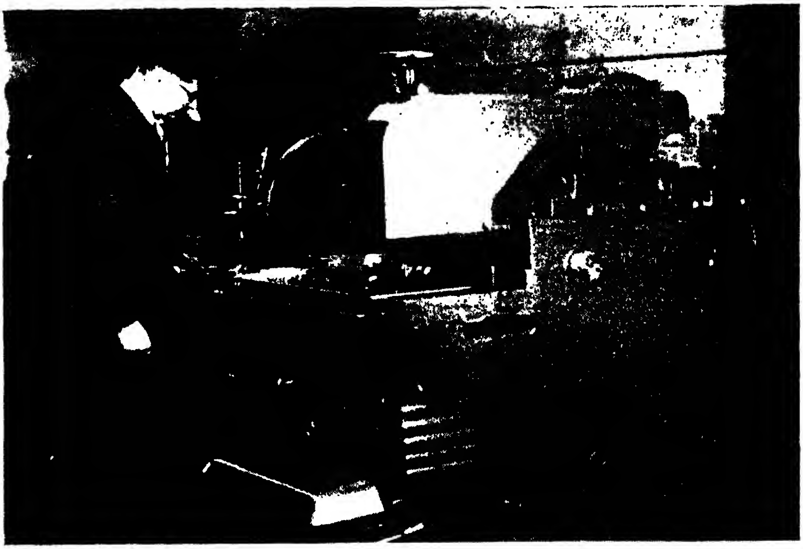


Fig. 100.—*Wadkin Spar ending-off machine.*

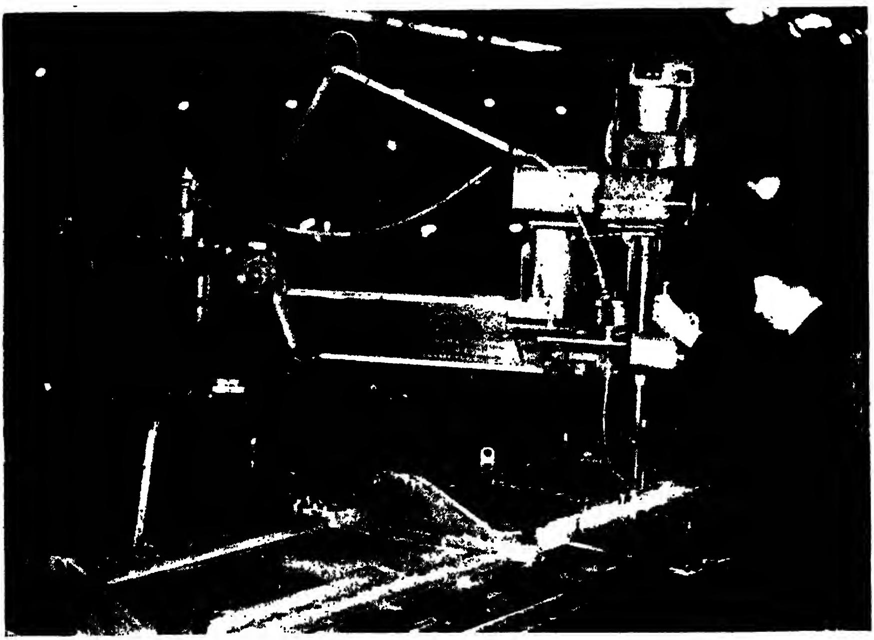


Fig. 101.—*Another form of Wadkin Spar Drill.*

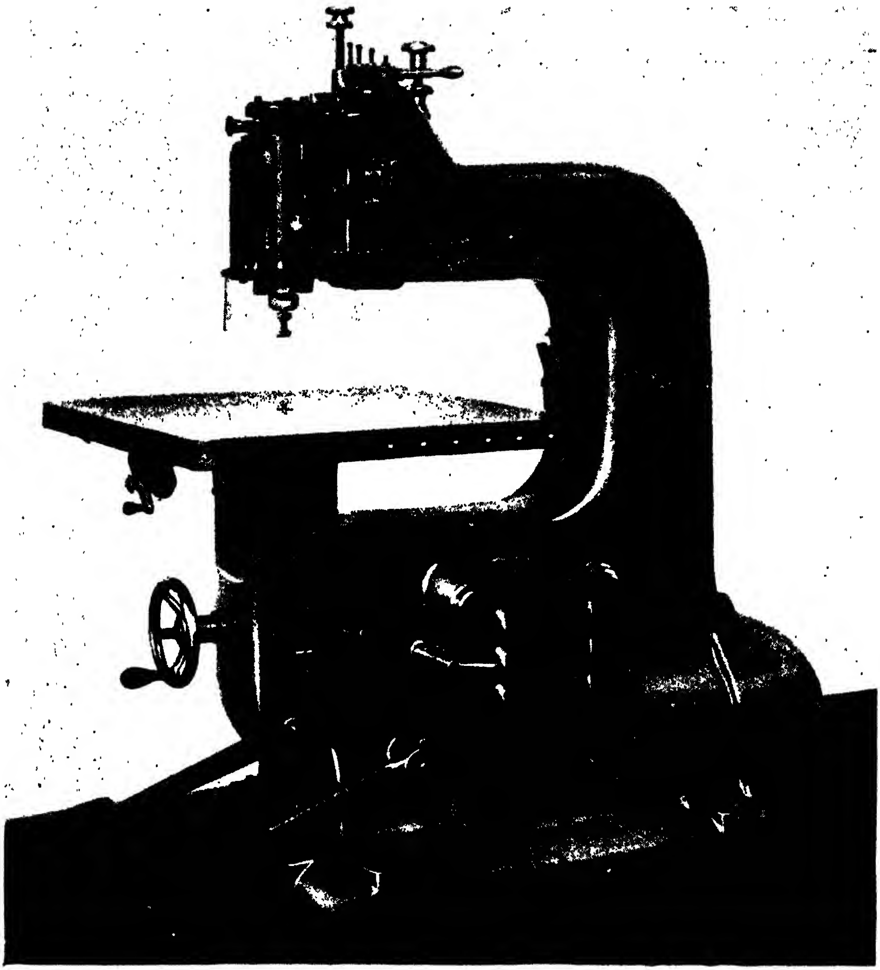


Fig. 102.—Wadkin Standard Metal Router.

engages, thus milling out the pocket. This can be repeated along the table to produce any number of pockets automatically, thus eliminating marking out and the possibility of error after the machine has been set up.

Wadkin Spar Drilling Machines

Much progress has recently been made on spar drilling machines, as will be seen in Figs. 99 and 101. Drills when of the radial type can be used on either table. This arrangement is very suitable on this type of work, as operators can be drilling on one table whilst operators are loading on the opposite side.

As a general rule, it has been proved quite impracticable to have movable jigs mounted on roller tables to bring the spar within the compass of the drill spindle, and it has proved to be sound practice to build the long drill jigs permanently on the drill

tables and provide travelling radial drills to cover the length of the spars. This arrangement has many advantages, including the very important one that any number of heads can be fitted to balance the drilling time on the various spars.

A feature of these radial arm drills is the ease of operation, power locks being provided to reduce fatigue and time to a minimum. The installation of these machines has resulted in the production per operator being doubled.

Wadkin Spar-Ending-Off Machine

This machine has recently been introduced for cutting off spar extrusions to length. The spar is clamped on a fixed table and the geared saw head, mounted on a horizontal slide, comes forward and cuts through the spar. This slide is controlled by a hydraulic cylinder and is infinitely variable in feed, and the control is by foot lever. A milling head can also be fitted on to the spindle in place of the saw and used for milling the ends of spars, the spindle being speeded up by fitting a change pole motor drive to the spindle. The maximum capacity of this machine is eight inches by four inches deep. Fig. 100 shows a short table, but this can be supplied to any length, and fitted with rollers to facilitate handling.

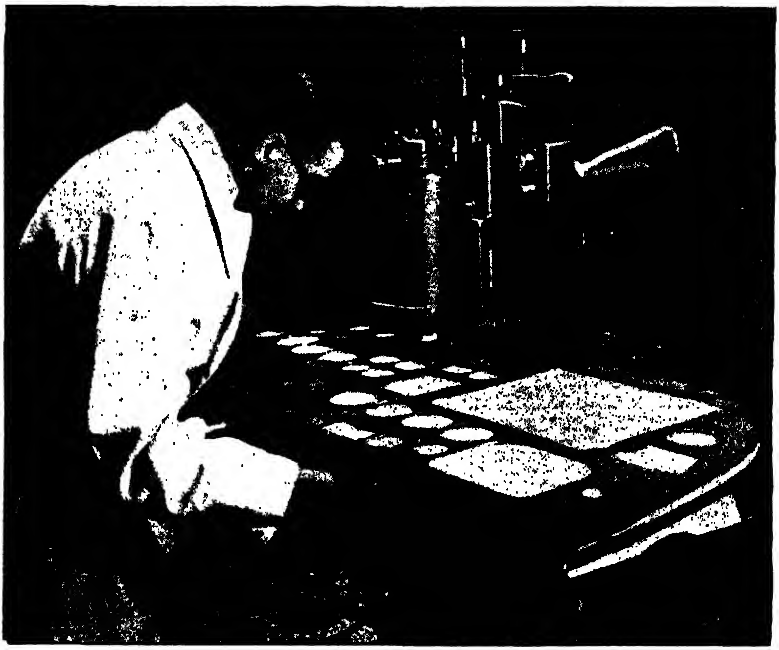


Fig. 103.—Fixed Head Router on instrument panels.

Wadkin Standard Metal Router

The machine consists essentially of two slides mounted in line on a main frame. On the upper slide is mounted a head consisting of a high frequency motor, carrying the cutter, and on the lower, a table, which is provided with a guide pin. The rotor shaft, which is really the spindle, is mounted on a special single row bearings fitted with fabric cages lubricated by grease, rotates at 24,000 r.p.m. and carries cutters of various diameters up to $1\frac{1}{2}$ inches. The cutter is exactly over the guide pin and the method of working is to use a jig having the template on the underside and the metal to be cut to shape located on the top. This jig is then pushed past the cutter, the template and guide pin being in contact until the profile is completed.

This machine is suitable for thickness of sheet up to $\frac{5}{16}$ inch, although $\frac{3}{16}$ inch is best, and equally suitable for internal and external profiling. Thin sheets can be stacked up to $\frac{3}{16}$ inch or $\frac{1}{4}$ inch thick and cut in multiples.

The feed is from 4 to 10 feet per minute, depending upon the shape of the profile being cut. The finish is clean and accurate to plus or minus 0.010 inch although accuracy of plus or minus 0.003 inch can be maintained by taking special precautions in the jig and cutters. The router will deal with approximately 1 ton of sheet material per week working single shift, but of course, many of these machines are running 21 hours per day and 7 days per week. Cutter wear due to re-grinding can be allowed for by using undersized guide pins in the table. The machine is suitable for aluminium, alclad, dural and brass sheet, and some copper has also been cut. The machine is being used principally by the aircraft industry and there are about 1,000 in use on metal cutting.

The alternative to routing is the use of press tools, which are generally large and expensive, especially when the cost of punches and dies and the labour involved are taken into consideration; furthermore, the rate of modification of design practically eliminated the press for blanking aircraft parts, because of the shortage of tool makers and the obsolescence for punches and dies before they were completed. This compares with a hardwood board, a steel template in $\frac{1}{8}$ inch thick mild steel and a few $\frac{3}{16}$ inch bolts required to produce blanks on the router.

Another advantage is that any number of jigs can be used to produce a given number of sets or parts per hour. Juniors can be used for reloading the jigs to save the operator's time. The machine is also suitable for half lapping and scarfing operations on sheet.

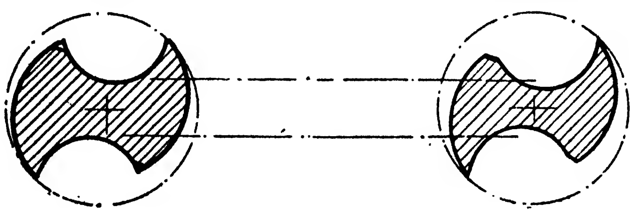


Fig. 104.—Dural Cutter on the left; Alum. and Alclad Cutter at right.

Wadkin Fixed Head Router

Fig. 103 shows the production of aeroplane instrument panels in sheet dural. The sheets are first drilled to a template so that they can be mounted on the studs in the jigs and clamped up. It will be noted that internal and external cutting are equally convenient, the operator lowering the head with a foot treadle, so that both hands are free to manipulate the jig. The head is spring loaded and returns to the top position when the spring ratchet is released by the operator's toe. The cutters are designed for piercing the sheets, so that preliminary holes are not required for the entry of the cutter. The production time for two of these sheets in 12 gauge would be about ten minutes.

As regards cutters for this machine, the best size for cut out sheet work is $\frac{3}{8}$ inch diameter, although $\frac{1}{4}$ inch and $\frac{1}{2}$ inch are often used. The cutters have been developed almost entirely by experiment, although the original approach to the problem was the trial of wood cutters. The cutters now in use have two spiral cutting edges and smooth well rounded flutes to assist chip clearance. They are made of high-speed steel.

Cutter Profiles

Referring to cutter maintenance, it is a fundamental of all router work that cutters must be stoned after grinding, before using. The cutters are stoned on their periphery, and this process can be repeated with very beneficial results, say every hour, for five or six times, until the cutter requires re-grinding. This is done by grinding in the flutes and then re-stoning before use. Sections of the cutters are shown in Fig. 104.

Wadkin Radial Arm Router

This machine was introduced nearly four years ago to meet the need of the British Aircraft manufacturer for a machine to handle large sheets of dural, generally 8 feet by 4 feet and 12 feet by 4 feet and sometimes 24 feet by 2 feet.

The machine consists of a similar head to the other routers mounted at the end of an arm mounted on ball bearings and very easy to move about in the horizontal plane. The table which carries the jigs and the sheets can be supplied in any length up to

30 feet 0 inches and 4 feet 0 inches width. The table is fitted with rollers which are mounted on rails fastened to the floor, and when one portion of the sheet has been routed (about 5 feet 0 inches in length), the table can be pushed along and the next 5 feet 0 inches routed, and so on for very long material.

Where high production is required, a table can be fitted on either side of the machine and a youth can be employed to strip and reload one table while the operator is cutting on the other.

Fig. 105 shows the operator routing components on a table 24 feet 0 inches long. On this type of router the profile plate is mounted on top of the sheets and the head is guided by the operator, a guide bush around the cutter shank making contact with the templates. It will be noticed that several jigs are mounted on the sheets to make the best use of the sheets and eliminate large scrap panels. This is called nesting and several firms have reported a saving of up to 30% in sheet material by using this method of production. It is usual to plan these parts before going into production to decide how to obtain the maximum number of parts from each sheet, so that the operator is not left to arrange them for himself and this is controlled by the drilling jig.

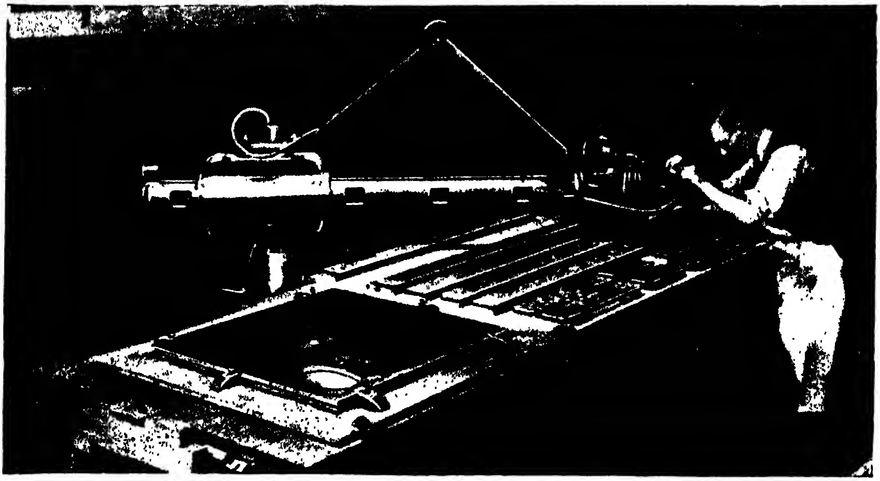


Fig. 105.—*Radial Router in operation on large sheet work.*

Adcock and Shipley Angular Hole Drilling Machine for Spars

Adcock & Shipley, Ltd., of Leicester, have produced a machine for drilling angular holes in spars, and this consists of a swivelling head which pivots from the centre of work table upon a large circular slideway, this system keeping the drilling pressure in the centre of the work table.

The drilling spindle is a modified form of their type " R " radial drilling machine saddle, with six speeds from 400 to 1,600 r.p.m. and three automatic feeds from 90 to 200 r.p.m., as well as fast sensitive and slow hand feeds. The sliding spindle bracket has vertical adjustment on the saddle for setting up purposes, etc.

The swivelling motion is obtained by handwheel operating sprocket wheel on chain contained in a groove of the circular slideway.

Adcock and Shipley Universal Spar Milling Machine

This Spar Miller may be described as universal, in that it is capable of milling spars having angular variations of 12° from one end to the other. The amount of twist which can be machined ranges between 3° outwards and 27° inwards. Additionally the machine can be used for straight or taper milling, so that there is a very definite advantage over machines which are only built for straight milling.

An important feature of the spindle drive, direct from motor by vee ropes, is that belt tension is taken by the spindle sleeve, so that all strain is eliminated from the spindle itself. Electrical control is provided by radial arm carrying push-buttons from back or front of machine.

Knight Milling Machines

The Knight Milling Machine is one of the range built by the Knight Machinery Company, St. Louis, Mo., U.S.A., who are represented in this country by the Broadway Engineering Company, Ltd., Carlisle Road, Hendon, N.W.9. Three sizes of vertical millers are produced, Nos. 20, 30, and 40.

The column is a semi-steel casting, cast integral with the base. Fitted in the lower portion of the column are a large post and trunnion, into which is assembled the table unit. An outer support is provided to stiffen the table assembly. The large bearing surface on the column, on which the spindle head travels, is scraped to surface plates, and other bearing surfaces on the table, saddle and knee are similarly finished.

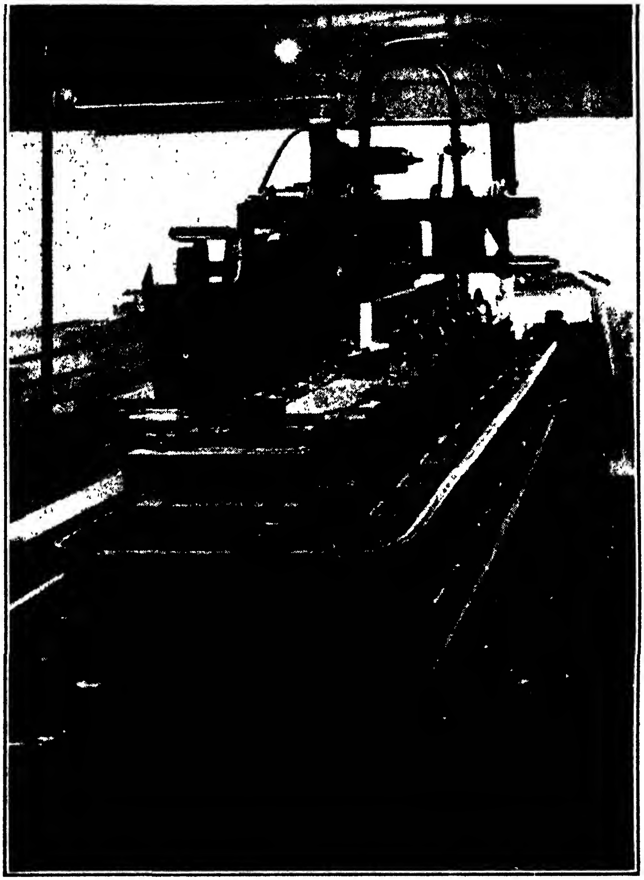


Fig. 106.—Milling a centre-section rear spar boom on a Sunderland Traversing head machine.

The spindle, which is of high carbon manganese steel, is mounted in an oversize quill, on tapered roller bearings. The spindle travels on a slide on the face of the column, and is securely held in any position by a positive locking device controlled by a single lever. Anti-friction ball bearings are used to carry all shafts, and lapped spiral bevel gears transmit the spindle drive. The spindle head can be adjusted vertically, and this, with the extra long travel of the spindle in the head and the swivelling of the table unit around the column, adds to the machine's capacity. Sixteen changes

of speed, in either direction, varying from 40 to 2,000 r.p.m., according to the size of the machine, are provided, and the four vertical spindle feeds range from 0.002 inch to 0.010 inch per revolution of the spindle. Sixteen table feeds are obtainable in either direction. Speed and feed controls, with large dials, are centralised on the left-hand side of the machine. The construction of the table unit allows it to be tilted 35° to either side of horizontal for angular cutting. This motion is carried out by means of a worm and gearing, with four T-slot bolts to lock the table in any position.

A graduated segment gives the position of the table in degrees. All tool changes are made at the spindle nose, and the spindles are furnishedwith standard B. & S. taper and an adapter. The adapter, with a driver fitting into a square machined on the inside of the spindle nose, is drawn into the spindle taper by a large knurled collar. When the clutch is disengaged a brake on the main shaft stops the spindle immediately.

Clare Milling Chuck

Perhaps the greatest problem in the machining of metals is that of holding the tool against the thrust of the work. This problem is even more evident when the shank of the tool is of parallel circular section, and there is always attendant the risk of the tool slipping as the pressure of the work becomes too great. This usually results in the breakage of the tool or damage to the surface of the metal being machined.

If this difficulty can be overcome successfully then the operator can concentrate on the work being machined and be assured that the cutting tool will not fail by slipping in the collet or sleeve which holds it. This problem is solved by the use of Clare Milling Chucks, using milling cutters even up to eight inches in diameter on the heaviest cuts. Slipping of the cutter is made impossible by the tang which is cut on the end of the shank.

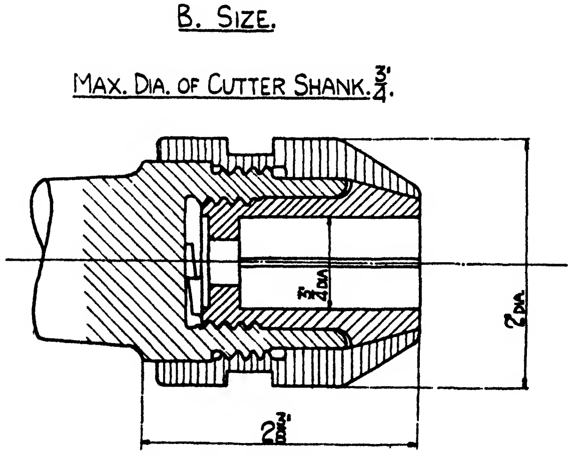


Fig. 107.—*Clare Milling Chuck.*

When R.H. quick spiral end mills are used there is always a tendency for the mill to creep out of its housing. This lateral movement of the mill is even more undesirable when using T-slot cutters, and in many other cases. It is, however, altogether dispensed with when using cutters with the Clare patent latch.

The length of the shank on the Clare Patent Mill is made to conform with B.S.S.122, and this enables the tang and latch to be ground on any standard shank.

Clare Drilling Chuck

The patent drill chuck is manufactured in five sizes, the maximum parallel shank taken being 1½-inches and the maximum Morse shank taken No. 5.

These chucks can be adapted to a variety of purposes, as drilling, boring machines and turret lathes. The chuck is self-centring and slip is impossible; as the drill meets with greater resistance the tendency to rotate the collet in a L.H. direction screws the collet out (as it is screwed L.H.) and brings it to bear with even greater pressure against the cone of the coupling. This pressure bears on the shank of the drill and not on the tang, so that tangless drills can be used quite efficiently.

Incandescent Heat Co. Automatic Salt Ejector

Users of salt bath furnaces unanimously approve frequent clearance and changes of salt as the most effective method for maintaining the ideal chemical balance, freedom from contamination, and corrosion of work; and—of equal importance—obtaining

the longest possible life from the pot or container. Hitherto, the lack of rapid and effective means of salt transfer has seriously impeded regular cleaning out, and, under stress, such operations are often deferred until bath failure is apparent.

Present methods of discharge, viz., ladling out and cutting out of the molten and frozen salt, involve considerable risk, expense, and loss of valuable production time. The Incandescent Automatic Salt Ejector reduces the discharge effort to electric push-button action, and the time factor from days to minutes. On test a 15-tons capacity salt bath was completely emptied in about twenty minutes. Consequently, weekly or monthly cleaning out and inspection cycles may be adopted with the ease and simplicity of the average plant maintenance task.

The ejector, which is, in effect, an inverted U tube, has the suction leg fully immersed in the molten salt, with the delivery leg arranged to discharge the salt into the catch pit or other convenient storage receptacles. The whole unit is portable and readily assembled and dismantled as required. It may be suspended from above or, if working space permits, be made a permanent fixture and fastened to the bath casing.

The control unit is located as near as possible to the ejector, and both units are coupled together by a copper connecting tube. The complete assembly is ready for operation immediately after plugging in the control unit to the electric mains.

The outflow of salt is under complete control and may be intermittent or continuous, the rate of discharge being adjustable to suit the storage facilities available. The motor can be supplied suitable for A.C. or D.C. supply at customary voltages.

The ejector unit will operate satisfactorily on baths of all capacities and its proportions may be arranged to suit the dimensions and design of any furnace unit. The control unit is manufactured in several standard sizes up to a maximum continuous discharge capacity of 25 tons per hour.

Incandescent Heat Company's Salt Baths

Solution treatment is a vital and well-established process in the manufacture and manipulation of light alloys. The exigencies of modern specifications for both material and treatment require a high degree of skill in salt bath design and execution, and the ever increasing demand on production capacity necessitates the highest possible efficiency, flexibility and economy on the part of the plant installed.

The trend in design of modern production plant is towards automaticity both in operation and control. Sheet normalising treatment can be carried out in a gas-fired unit combining two-stage firing, two-zone automatic control salt bath, and quenching, washing, and sheet handling equipment

A unit for the treatment of medium-length airframe details, supplied to a Midland factory, has multi-zone indirect firing, and power operated covers.

General purpose heat treatment units are supplied completely equipped with automatic control and recording instruments. These units are ideal for light production and will meet all the requirements of the smaller manufacturer and sub-contractor engaged on light presswork; hand beaten sheet work; fuel tanks and a wide variety of components which are employed in present-day aircraft construction. Quenching and washing tanks, also fume extraction equipment can be supplied to specification.

An outstanding feature in modern aircraft design is the extensive use of lengthy extrusions and rolled products to form main spars, struts, general wing and hull members. This combined with the trend towards single-piece construction of wing tip covers and fairings has led to the use of salt baths of exceptional working length. I.H.C. installations up to 30 feet long-20 tons salt capacity are now in regular production and giving highly satisfactory performance.

Cylindrical or rectangular baths are used for the treatment of aluminium covered and unprotected alloys in the form of stampings, pressings, forgings and rivets. These baths may be fitted with geared hand-operated covers, or horizontal acting sliding type.

Ross Operating Valves

In aircraft production, Ross air valves are used for air chucks; safety control of power presses; welding, die-casting, and riveting machines. Models include hand, foot, mechanical and solenoid controlled types.

Positive sealing of valve seats is assured by line pressure exerted against underside of metal cup washers, in which synthetic oil resistant rubber is permanently vulcanised. Airtight service over long periods of use reduces maintenance costs to a minimum.

Working parts, quickly and easily installed, are interchangeable between different valves in like sizes, eliminating the necessity of large replacement stocks. No lapping

or grinding is required. All ports are on one face. The valve may be mounted on a bracket in which piping is permanently installed. This makes servicing simple and keeps machines operating.

Ross Operating Valves are of two types—locking and non-locking. When the lever of a locking type valve is moved by the operator to either working position, it remains there until again moved by the operator. In the centre or neutral position both exhaust valves are slightly lifted off their seats, thus opening both ends of the cylinder to exhaust, eliminating the possibility of accidents due to creeping of the piston. For certain applications where a vertical cylinder is required to sustain a load at a certain height, this adjustment is altered.

When the lever of a non-locking valve is released by the operator it automatically returns to the neutral position in which both exhaust valves are slightly lifted, as for the locking type valves.

The body design, with all ports on one face, is such that Ross operating valves may be mounted in a position to give any desired motion of the lever. Where it is necessary for an operator to control a number of valves, this design makes possible a multiple mounting in a minimum space.

SMALL TOOLS

Portable Electric Tools

WHILE intensive production owes much to the developments in machine tools, it is equally true that high-speed assembly is due to the collateral developments in portable electric tools. This is particularly the case in the newer industries, such as aircraft, where the requirements of light metal construction and awkward position work, necessitate the use of tools possessing high speeds and light weight.

Fortunately for present conditions, such tools are available in a wide range of types and sizes, as illustrated in Figs. 108 and 109 showing two types of portable tools by Black & Decker, Ltd., Harmondsworth. Fig. 108 shows the Holgun, one of a range of four light, compact machines easily controlled with one hand, and suitable, for example, for drilling parts held in intricate jigs. Where low spindle offset is essential for close corner work, this tool can be fitted as shown with a flexible drive which reduces the offset to $\frac{3}{16}$ inch. The capacity of the drill is $\frac{1}{4}$ inch in diameter in steel; the weight $2\frac{3}{4}$ lbs., while the overall length is only $6\frac{3}{4}$ inches. A low-speed model is also available with a speed of 500 r.p.m. for drilling in stainless steel, monel metal and other modern hard alloys.

Heavy duty drills with capacities up to $1\frac{1}{4}$ inch diameter have ball and needle roller bearings to ensure smooth running and withstand severe side and end thrust. An automatic release trigger gives rapid and safe control, while the power and slow speeds obtained by triple reduction gears make them suitable for heavy engineering purposes. This $1\frac{1}{4}$ inch model has a weight of $28\frac{1}{4}$ lbs. with an overall length of 20 inches.

Although designed for portable operation, these tools find useful application when mounted on bench stands or on a radial arm, in which case they become virtually high production machine tools of great utility in any engineering plant.

The success of many production lines is also due mainly to the introduction of other portable electric tools, built by Black & Decker on similar lines to those described. These aids to output include screwdrivers and forsimeters which predetermine the torque applied, so that each screw is released at the same tension point. Similarly, electric nut runners ensure uniform work, and automatically disengage when the driving pressure is released. The range is extended by bench and portable grinders, attachments and accessories for every type of tool as well as portable electric saws for timber cutting. Fig. 110 shows the "Ripsnorter" saw, made in three sizes with a blade diameter of 7, 8 or 9 inches, and arranged to cut to a depth of $2\frac{3}{8}$, $2\frac{5}{8}$ and $3\frac{1}{8}$ inches respectively. The portable saw is many times faster than hand sawing, and is easily carried as the weight of the heaviest pattern is only 26 lbs. Also its use is not restricted to timber cutting, but may be extended by suitable blades to include the cutting of non-ferrous metals, slate, marble, asbestos and similar materials.

In addition to the usefulness in general engineering machine erection, portable electric tools are particularly handy in building construction or where walls have to be drilled for piping or bracket supports. These operations performed by hand are tedious

and long, whereas by electric drilling, neater work and probably 75% of the time is saved. The advantages are even more pronounced, for certain of these tools can rapidly be changed for other operations in a matter of 30 seconds. The Climax Wodack "Do-All" (Climax Rock Drill and Engineering Works, Ltd., London) electric drill, Fig. 111 for example, is a universal tool suitable for use in all erection and maintenance work.

In addition to drilling up to ⅜ inch holes in metal, brick or concrete, it can be rapidly converted for grinding, scratching, buffing or changed to an electric hammer drill for boring holes up to 1⅜ inch diameter in concrete or masonry, or brick. The tool has several unique features, the hammer member is constructed without a nut, bolt, or screw so that loosening of any part is eliminated. The electric motor is of a universal type, air cooled by a large fan, with the armature shaft running in ball bearings, and the spindle in adjustable Timken taper roller and ball bearings for radial and end thrust respectively. There are only two working parts in the hammer member, and the thrust which is set up during drilling is taken by precision ball bearings. The weight of the drill itself is 12¼ lbs. and when fitted with the hammer attachment, 18¼ lbs. The complete equipment which includes various accessories and a steel container to hold the machine and tools is 44 lbs.

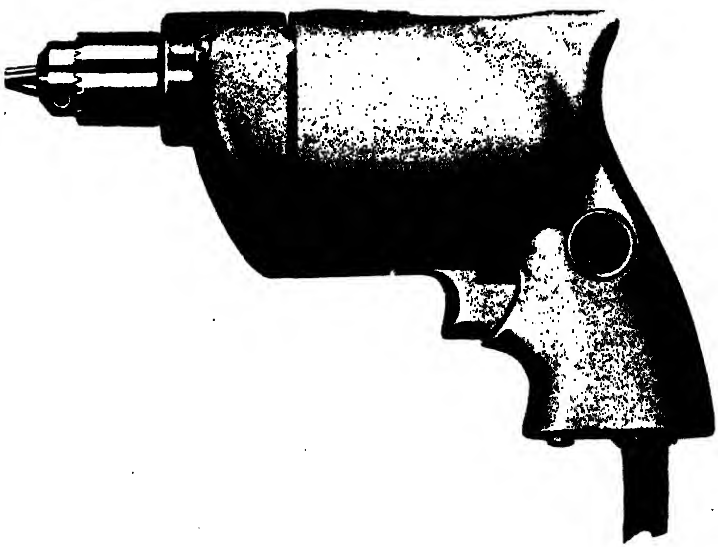


Fig. 108.—"*Holgun*" *Portable Electric Tool.* (*Black & Decker, Ltd.*)

A speciality of the Climax Company is the use of compressed air, and portable and stationary compressors have been designed with outputs from 45 to 325 cubic feet per minute. F.A.D. at 100 lbs. per sq. inch pressure. Sixty years' experience in this direction has been applied to the manufacture of pneumatic tools, including chipping hammers, riveting hammers, pneumatic sand rammers for foundry work or making concrete blocks and structures.

Another development is a pedestal grinder suitable for sharpening drills, chisels or other hand tools. The grinding wheel is 8 inch diameter by 1¼ inches wide, but wider wheels up to inches can be supplied. The drive is by an air motor, accurately constructed and balanced. The blades are of hard fibre, and kept in contact with the casing by stainless steel rollers working in a groove concentric with the liner. The wheel speed is 3,500 r.p.m. with a vitrified wheel or 4,200 r.p.m. with an elastic bonded wheel. The air motor responds instantly to the depression of the operating foot lever, enabling the maximum torque to be obtained in a minimum of time.

Air Compressors

A wide range of Air Compressors both portable and stationary type is produced by The Consolidated Pneumatic Tool Co., Ltd. Stationary compressors are made in sizes up to 20,000 cubic feet per minute and for pressures up to 500 lbs., portable compressors can be supplied in sizes up to 900 cubic feet per minute.

Pneumatic Tools

The use of compressed air is finding increasing application in engineering production, particularly for work-holding devices, and its use in this direction is meeting with the same success that has attended its application to portable tools.

These pneumatic tools include riveting hammers, chipping and caulking hammers, screwdrivers, nut runners, drills, saws, shearing machines and grinders, to mention some of the productions of The Consolidated Pneumatic Tool Co., Ltd., London. The rotary vane principle embodied in drills and similar tools has been developed to give the maximum horse-power per pound of weight. The construction is simple and

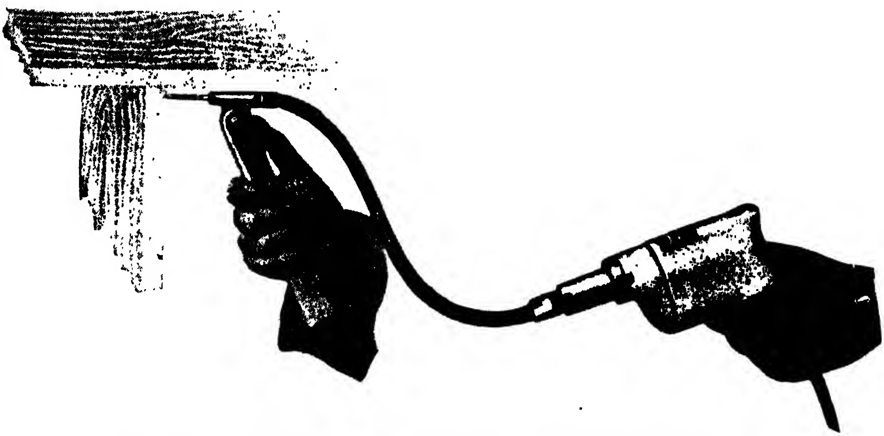


Fig. 109.—" *Holgun* " *with flexible drive.* (*Black & Decker, Ltd.*)

obviates use of pistons, toggles and crankshaft. The motor being in perfect balance, assures smooth operation without vibration, while a governor prevents racing as well as reducing the air consumption. Ball bearings are used throughout, and interchangeable gears give wide speed ranges. Both non-reversible and reversible types are made.

Pneumatic drills with a capacity from $\frac{1}{8}$ to 3 inches are manufactured, the small size finding great application in the aircraft and similar light duty industries, while the larger machines are equally useful in general engineering work, where heavy duty capacity makes them particularly serviceable. Machines for close quarter work are made.

Typical examples are shown in Figs. 116 and 117, showing drills with capacities of $\frac{3}{8}$ to $\frac{1}{2}$ inch drilling or reaming, and tapping up to $\frac{5}{16}$ inch. It will be seen that either piston grip or screw feed can be used.

Stationary air motors for adapting to users' own driving purposes are manufactured to transmit from 2.75 to 5 h.p. according to the size selected. Other interesting applications include safety balancers to lift, suspend and balance portable tools up to a weight of 200 lbs. Similarly, the application is carried further to wire rope or chain hoists with a lift varying from $\frac{1}{4}$ to 5 tons.

Care of Pneumatic Tools

A clean supply of air is the first necessity, so it is essential to see that the suction pipe on the compressor is not placed where it can draw dust of any description, and also that the hose pipe when disconnected from the tool, is not laid down where grit can lodge in the connector and be blown into the machine. This is a frequent source of trouble, and air should be blown through the hose before connecting up, this will remove moisture as well as dust.

Keep the air mains and receiver well drained, and see that the coupling between the cylinder and handle is kept tight. After use, a pneumatic hammer should have a charge of oil blown through it to remove moisture, which might otherwise be left in after the day's work. Use the best possible light oil for hammer, and heavier oil for the drills. Do not allow drilling machines to be run light with an open throttle.

Hycycle Portable Electric Tools

Consolidated Pneumatic Tool Co., Ltd., produce a machine operating on a high frequency of 200 cycles which, with a 2-pole induction motor, gives a rotor speed of 12,000 r.p.m. synchronous. This speed is maintained under all conditions of load and is geared down to suitable spindle speeds, which ensures that twist drills, grinding wheels, etc., are running at correct cutting speeds, which, combined with high motor power, gives a large increase in productive capacity. The advantages over other types of portable tool are thus very striking. Universal electric tools have a big speed drop and their wound armatures are susceptible to overload, making them unsuited to heavy

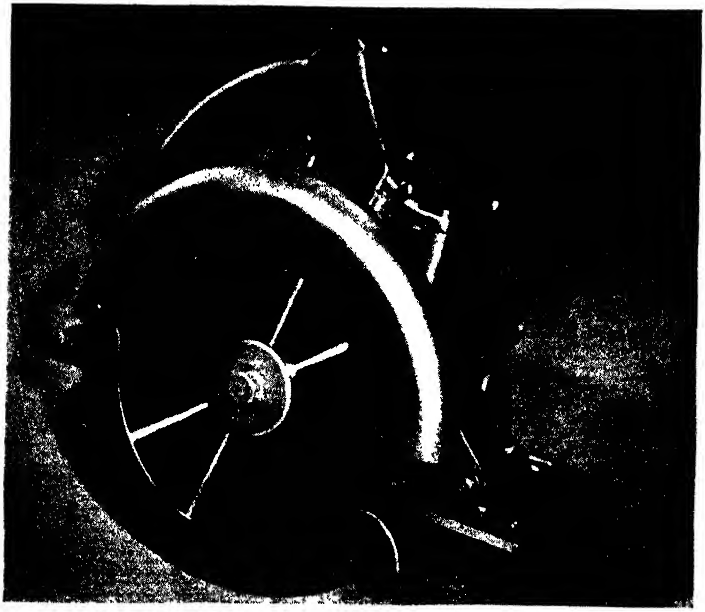


Fig. 110.—*8 inch Ripsnorter Saw.* (*Black & Decker, Ltd.*)

continuous production conditions, whilst compressed air tools are expensive to operate, requiring about five times the power input for the same work as a Hycycle tool. The Consolidated Pneumatic Tool Co., Ltd., have developed a range of Hycycle portable electric tools, including drills, screwdrivers, nut runners, sanders and grinders, all of which are available in many types and sizes for all machine shop purposes.

Universal Electric Tools

While compressed air and Hycycle tools are recommended for production conditions there remain countless miscellaneous operations where the heavy production machines are impracticable. To meet this demand the Consolidated Pneumatic Tool Co., Ltd., have one of the most comprehensive and well-designed ranges of Universal electric tools, with a machine for every job. Drills range from tiny $\frac{3}{16}$ inch models of a little over 3 lbs. in weight to 1 inch capacity models of 27 lbs., with a similar wide range of screwdrivers, nut runners, grinders, etc.

Desoutter Pneumatic and Electric Tools

The portable tools manufactured by Messrs. Desoutter, Ltd., Colindale, cover a wide range of pneumatic and electric tools adaptable for general and special machining operations. The " Mighty Atom " range, for example, are representative of the pneumatic type, and are claimed to be the smallest, lightest, and most powerful of this type in the world. They are suitable for a great variety of work, each one being designed with correct speeds for a specific purpose and perfectly balanced for one-hand operation, for the lightest tool weighs only 12 oz., and the heaviest only $2\frac{1}{2}$ lbs.

Fig. 114 shows a section of the tool with the vane type motor used in its operation. All the gears and rotating parts are made from chrome-nickel-molybdenum steel, hardened and tempered, with every bearing of ball or roller type, so that apart from lubrication, servicing or other attention is reduced to the absolute minimum. From the rotor shaft to the chuck spindle, the drive is by epicyclic gearing, while the blades of the vane type motor are of special reinforced bakelite composition, ensuring long life.

This and other pneumatic types are available for straight and corner drilling, shearing, nibbling, screwdriving, and nut running, as well as for specialised work. One interesting tool for the latter category being a pneumatic twin spindle drill for drilling the rivet holes for Simmonds Nut Plates. After the clearance hole for the central bolt is drilled, a centre spigot on the two spindle drill is located in the hole, and the two rivet holes drilled in one operation at the correct centres. The weight of this complete tool is only 2 lbs. and the air consumption $6\frac{1}{2}$ cu. ft. of free air per minute.

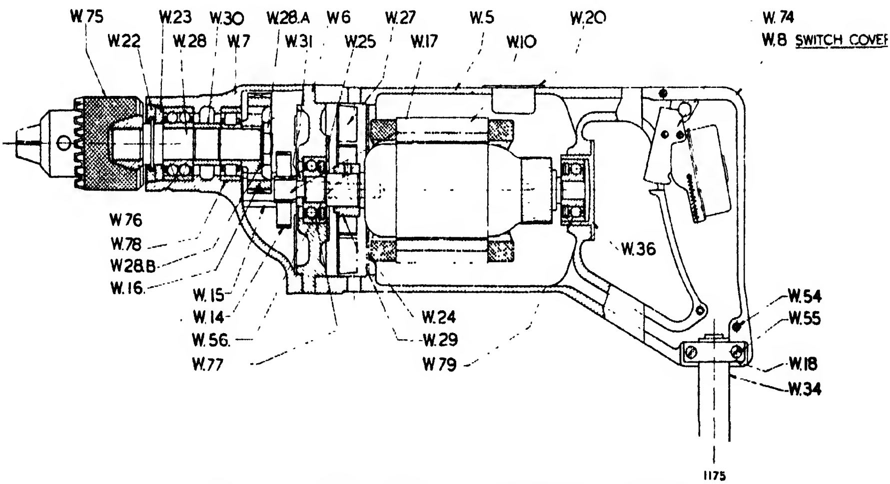


Fig. 111.—Climax-Wodack " Do-All " Electric Drill.

The Desoutter electric tools are equally adaptable, and of correspondingly light weight. Special attention has been given to motor design, and for the first time in motors of this size, former winding as used in large motors has been adopted. The process needs highly skilled labour and takes ten times as long as machine winding, but results in a tool capable of heavy duty and with long life. The " Streamline " electric gun drill, for example, will drill a hole $\frac{1}{4}$ in. diam., $1\frac{1}{2}$ in. deep in one minute, and before the design was released, passed a test of 300 hours, full load running, non-stop. The temperature rise permitted in B.S.I. specifications is 80° F., yet so efficient is the cooling system that under continuous full load the temperature rise does not exceed 60° F.

Drill guns of the latest types include not only corner guns, but one with 180° return. The former enables holes to be drilled within $\frac{1}{8}$ inch of the face of a right angle.

There is now an adjustable nose counter-sinking drill in various sizes; and a telescopic-nose jig drill, for either pneumatic or electric drive, with its own hardened steel jig bush, which drills up to 16 s.w.g. The big savings incurred by the use of these tools pay for their original cost many times over. For instance: hardened jig bushes

are unnecessary and instead of a proper jig, all that is required is merely a simple template. The twist drill is fully protected inside the jig tool until the nose of the tool has engaged with the template, consequently drills last and remain sharper much longer. A further saving is gained by the speed of working, for with very little experience it is simple to drill 100 holes a minute.

Screwguns and Nut-runners

For high-speed assembly work, the advantages and economies gained by the use of these tools are obvious. The screwgun, by the simple addition of a box-spanner unit,

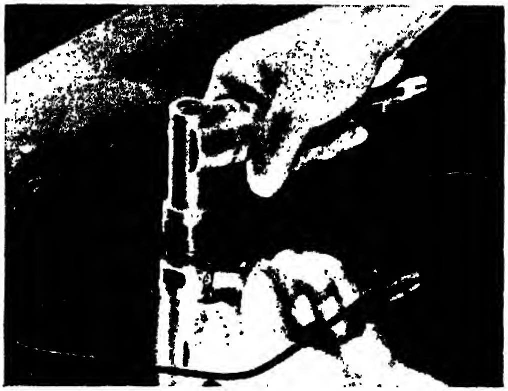


Fig. 112.—*Desoutter Nibbler.*

becomes a nut-runner. For screwdriving, a spring-loaded sleeve in the nose of the machine automatically centres the bit in the screw head and avoids slipping. Each screwgun is supplied with one bit and sleeve.

The spanner is an invaluable machine for running up nuts up to ½-inch capacity at high speeds. The box spanners are readily interchangeable, being retained by a spring-ball location and are fitted to either side of the hexagonal socket according to the direction of rotation required. Extra tension can, if necessary, be applied by hand, using the tool as a ratchet spanner with the control valve depressed.

Fig. 113.—*Twin Spindle Drill for drilling rivet holes for Simmonds nut plates.*

Nibbler

The Nibbler is a new tool for cutting sheet metal and is intended for use with a template or by using the radius-arm attachment, for cutting circles. The nibbler makes it possible to cut any shape whatever even out of the centre of a metal sheet, in which case a 1 inch hole is drilled, allowing the tool access to the work. The result is a clean cut 7/32 inch wide with perfectly clean edges, no burr and without deforming the sheet. It will cut to within ⅛ inch of a template and can be turned in a radius of 1 inch.

Tapping Machines

The Desoutter Tapping Machine is an extraordinarily efficient portable tool for the rapid tapping of small holes. The tapping head is equipped with a self-centring chuck to take different size taps, and operated on the push-pull principle, the tapping speed being 800 r.p.m., reversing as withdrawn at double the speed.

Bolt Milling

This tool overcomes the laborious use of a hack saw or file when getting rid of the unwanted shank of a bolt after a nut is tightened down. It is possible to regulate the tool so that any predetermined length of shank is obtained. The twist drill cutter is ground flat so that when each operation is completed, the end of the bolt can be locked by the usual centre punch method. Alternatively, the twist drill can be ground to a slight point when the shank end of the bolt will be left slightly hollowed out. A tap with a hammer will then rivet the shank over the nut securely and neatly.

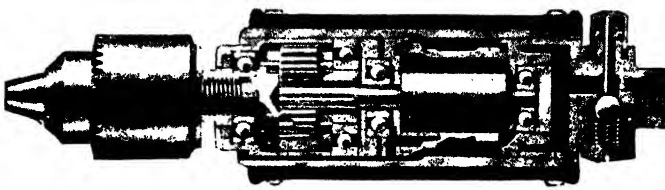


Fig. 114.—Desoutter Vane Type Motor.

Desoutter Grinders

The Model "O" Grinders have been specially designed for die sinkers and tool makers. Each machine is supplied complete with the following equipment: Model O.1 has six grinding wheels, two chuck spanners, one head spanner, ten feet length of hose, spare jet plate and one dressing stone. The outfit is packed in a wooden box. Model O.1.C has two grinding wheels, ten chuck spanners, one head spanner, ten feet length of hose and is packed in a cardboard box.

Funditor Squeeze Riveters

Light-weight hand squeeze riveters are becoming increasingly popular in the aircraft industry, due to their ability to reach awkward places and freedom from pipe lines

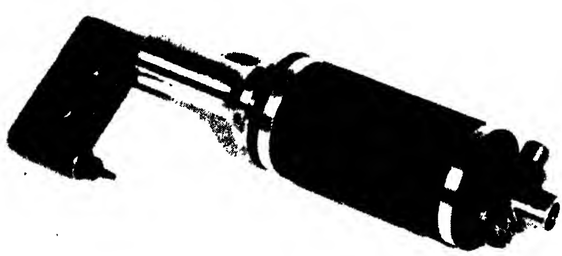


Fig. 115.—Drill Gun with 180° return.

which get in the way of the operators. They are also advantageous because they squeeze the rivet to shape before the rivet work hardens, which condition may occur when the rivet is subjected to hammer blows either when manually or mechanically applied. These tools are not made with throats deeper than five inches, which is about the practicable maximum if the hand riveter is to be kept within handable limits, their action to be quick and smooth, and the weight kept low enough for use by female operators.

A typical hand squeeze riveter that has a wide range of applications is the Funditor Universal Riveter, 914T, produced by Messrs. Funditor, Limited, of London. This tool is made with a series of several interchangeable high-tensile steel yokes, covering a variety of throat capacities. It weighs only 9 lbs. with the smallest yoke and 11½ lbs. with the largest yoke. Its main features are easy operation and the snaps are always in line, consequently the rivet heads are formed true with the axis of the rivet. The capacity of the snaps is adjustable, and in consequence over-squeezing of the rivets is eliminated.

The Funditor Retractable Riveter, 983, is very similar to the 914T, but has an additional advantage wherein the moving snap can be withdrawn, and so allowing

Fig. 116.—*Pneumatic Drill with pistol grip handle.* (*Consolidated Pneumatic Tool Co., Ltd.*)

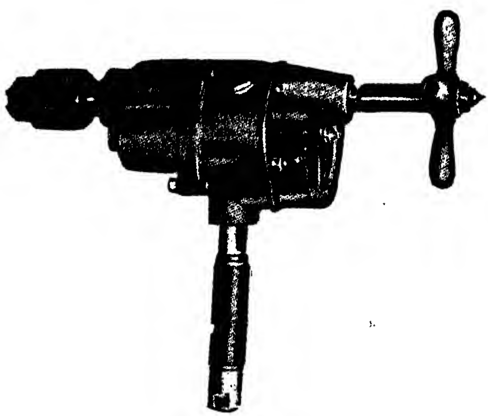


Fig. 117.—*Pneumatic Drill with feed screw.* (*Consolidated Pneumatic Tool Co., Ltd.*)

the tool to be passed over obstructions. The snap is then positioned and locked, and the riveting operation is performed, reversing the operations to remove the tool. This model weighs only 7 lbs.

With these two tools certain types of tubular rivets can be squeezed, but special snaps are necessary.

Further models are available, such as the Funditor Deep Reach Riveter, No. 420, and the Funditor Hand Riveter, No. 818. These two tools are pincer type and have also a wide range of applications. The model 420 has a standard reach of four inches, but greater reaches can be made to certain specifications.

Various types of standard snaps are available for flat and round head, mushroom and tubular rivets, and are interchangeable in all riveters, except the tubular rivet snaps, which are for the models 914T and the 983 riveters only. The sizes are normally 3/32 inch to 5/32 inch diameter of shank.

Another tool, the Funditor Countersinker, No. 679, is for punching holes and countersinking in one operation. This tool weighs only 2½ lbs., and its toggle mechanism gives a powerful movement at the snaps for a light pressure on the levers.

Broom and Wade Squeeze Riveters

In addition to manufacturing a complete range of percussive hammers, drills, shears, grinders, etc., Broom & Wade, Limited, have developed several designs of Pneumatic Squeeze Riveters which have met with extraordinary success. These machines have the additional advantage that they can be used for special forms of riveting such as the De Bergue type and " dimple " riveting. For flush riveting in plates which are too thin to be countersink drilled, the dimpling operation is carried out on the squeeze riveter.

The simplest type of machine in this class is the BSM range, made in three sizes and suitable for closing full cup head rivets up to 3/16 inch diameter in duralumin. The cylinder sizes are 6 inches, 9 inches and 12 inches respectively, and a very large selection of special yokes of varying reach and clearance is available. The machine consists merely of a piston and cylinder mounted on the yoke, with the moving snap carried in the end of the piston rod. There are, therefore, no moving and wearing parts beyond the piston and its rod. Foot-operated control valves are used, so that the operator has both hands free to manipulate the work.

Fig. 118.—Drilling skin panels on Defiant through boiler plate template jigs with conical holes for Desoutter self-centring attachments.

Owing to the size of the cylinder and yoke, the BSM machines are all of the stationary type. An example of a hand held portable squeeze riveter is the " Broomwade type SHH30. In order to reduce weight and size, this tool employs a small diameter air cylinder which exerts its load through an inclined plane and toggle gear, thus tremendously increasing the pressure at the riveting snaps. Actually, the force exerted increases progressively as the snaps close, and this is of course exactly what is required for riveting. This tool is arranged to screw into its yokes, so that any type of yoke, whether stationary or portable, may be used, and it will close rivets up to ¼ inch diameter in mild steel, or 3/16 inch in duralumin. A smaller size, SHH20, uses bolted-on yokes and is suitable for 3/32 inch diameter mild steel, or 5/32 inch duralumin rivets.

Perhaps the most interesting unit is the Hydro-Pneumatic Squeeze Riveter to which Messrs. Broom & Wade have devoted considerable research, and which has been the means of overcoming many difficult riveting problems. It consists of a large diameter air cylinder which concentrates its full load on a small diameter hydraulic ram mounted

in tandem. The resultant hydraulic pressure of 30 to 60 times the value of the air pressure used, is transmitted by means of a flexible hose to an " operating cylinder." The latter can be attached to any type of hand held or stationary yoke, with the result that snap loads up to 22 tons can be obtained in the most inaccessible places. Control of the unit may be either by remote push-button mounted on the actual yoke, or by foot-operated valve as required.

Morrisflex Flexible Shaft Equipment

B. O. Morris, Ltd., produce a range of bench and floor motors driving flexible shafts for rotary files and cutters. There is also an overhead suspension model.

Rotary cutters and files are suited for all materials from steel to bakelite. The flexible shaft drive can also be applied to wire brushes of all shapes, felt bobs, and non-flying mops.

Multiflex Machines

These flexible shaft machines, produced by F. Gilman (B.S.T.), Ltd., have been applied to grinding or polishing patterns and dies, the driving of a reciprocating filing head, a metal shear, or drills including a ten-to-one reduction.

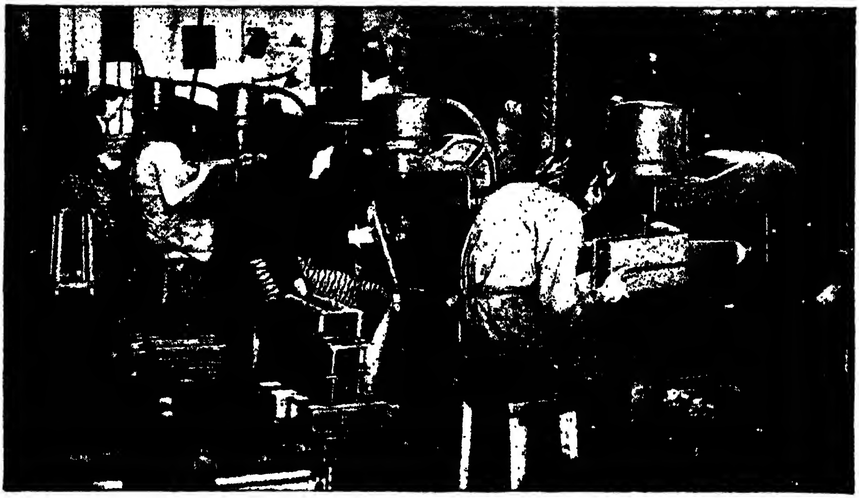


Fig. 119.—Group of Broom & Wade BSM 9 Squeeze Riveters.

Pilot Plug Gauge

The Pilot Plug Gauge is provided with a lead-in which permits it to enter a " size-and-size " hole without hesitation or jamming; whereas an ordinary plain plug gauge may require two-ten-thousandths clearance under difficult conditions of entry.

The lead-in consists of a circumferential notch close to the end of the plug. The chamfer of the notch lifts the gauge into line, making jamming impossible.

The fact that less clearance is required permits increased life of worn reamers; but this is only one way in which a Pilot gauge saves money: the others include the prevention of such trouble as a jammed plug moving the job and scrapping the component; the destruction of gauges by hammering in and out; damage to holes through the plug " picking up "; " doubtful " holes causing friction and argument between inspection and shops; the reduction of gauge wear; increased tool life; higher output; less scrap; and the deferment of expenditure on new machines.

Any good gauge maker should be able to supply Pilot gauges; or existing plug gauges can be easily modified under licence.

Besco Swing Beam Bending Machine

There is scarcely a bend or fold which cannot be performed by this machine, with its accessories. It is specially suitable for box or trunk forming, because of the swing beam which enables closed sections to be removed after being bent to shape. The smallest box shape or flue that can be made is 7 11/16 inch by 7 7/16 inch.

The bottom clamping beam and the front bending beam are independently adjustable to the bending centre. The top clamping beam can be raised to a height of 6¾ inches. By adjusting all three beams, tubes and channels up to 5½ inches can be made. The bending blade on the front beam is reversible, having wide and narrow edges. Small reverse bends can be formed without any difficulty. The front beam is adjustable

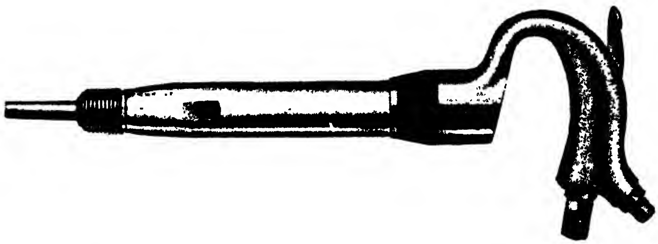


Fig. 120.—Broom & Wade Long Stroke Riveter.

4½ inches and the bed 4 inches. By using a roller, a complete round tube can be made in three operations. The bending blade in the top beam simply slides into position and is not secured by screws. The bending beam is counterbalanced and adjustable gauges are provided for repetition work.

The machine is supplied by F. J. Edwards, Limited, Euston Road, N.W.1. It will take sheet 80 inches wide and 14 s.w.g. thick.

Fig. 121.—Long spar being riveted on Broom & Wade Squeeze Riveter, BSM 9, with cradle mounting.

Boston Stitching Machines for Metal

The stitching together of light steel or other metal sheets by means of clenched staples as an alternative to other methods of fastening, such as riveting and spot-welding, has for some time received considerable attention in the United States, and

has been more recently employed to a notable extent in that country in aircraft construction. It must be understood that in this industry steel stitching is not recommended for primary structures, though it is stated to be suitable for some types of secondary structures. Its main employment is, however, in non-structural work, such as ammunition ducts, air and heating ducts, baffle plates, insulation and anti-vibration material, mouldings, cowlings, fairings, and ammunition boxes.

Boston stitching machines may vary in detail, according to the particular operation usually carried out on them, but the general construction is the same for all the patterns. In the standard machines the distance from the stitching point to the front of the column is either 15 inches or 25 inches; thus, if a trunk or drum is stitched on a longitudinal seam, a total length of four feet two inches can be handled by changing the work end for end half-way through the operation. The stitches are in the form of staples, the legs of which are clinched with their tips pressing tightly against the material, though the other part may be slightly bowed. This is the normal practice, but a flatter, tighter clinch can be obtained for jobs in which the staple legs must lie flat against the work. The stitching operation is controlled by a pedal, thus leaving both the operator's hands free for manipulating the work. The normal arrangement

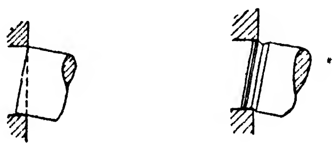


Fig. 122.—How Pilot plug gauge enters hole.

s for the stitches to be put in continuously as long as the pedal is depressed, there being a sufficient automatic delayed action between individual stitches to allow for adjustment of the work. This action can be readily converted into a single trip movement when very precise location of the stitches is desired, each stitch then requiring one movement of the pedal.

The stitches can be put in either longitudinally parallel to the edge of the joint, in an analagous manner to the stitches of a domestic sewing-machine, or they can be put in transversely to the joint, giving a ladder-like appearance, thus involving, of course, a wider gap. As regards speed, it is stated that, in certain cases where steel stitching has replaced riveting or spot-welding, some 75% of the time previously required has been saved. The advantages claimed for stitching compared with other methods of fastening are that no holes are required to be punched or drilled and lined up; the fastenings have not to be inserted by hand, screwed up or riveted over, and no heat liable to distort the work is developed. The method can be used to fasten other materials to metals.

The agents in this country are the Sheridan Machinery Co., Ltd., 74, High Street, Rickmansworth, Herts.

The Grampus Nibble Shear

The Grampus Nibble Shear was designed early in the war to meet the special problems arising in the mass production of metal components. Fresh developments show that it can be applied to the cutting of sheet metal in positions previously considered inaccessible. The machine is also capable of beading, tucking and seaming, and circle cutting. The cut is perfectly clean, requiring no deburring.

The Grampus nibble shear is manufactured in two sizes: No. 1 Model will cut up to 16 gauge mild steel; No. 2 Model will cut up to 10 gauge mild steel.

Funditor Marking Machines

Funditor Marking Machines are being applied to the marking of small aircraft components, instrument parts, both flat and round, in steel, aluminium, brass and bakelite, etc. The machine is solidly constructed, having the sliding head strongly

supported. This head has an adjustable, horizontal movement operated by hand lever, and a vertical screw adjustment to accommodate parts of various thicknesses.

The equipment available includes marking tools such as type, type holders, engraved knurls, roller-bearing cradles, ball bearing arbors, numerators, and special fixtures. Treadle, pneumatic and hydraulic marking machines can be supplied.

Application of the Vernijigger

For some time now, a strong need has been felt in the engineering world for a cheap, convenient means of accurately drilling and marking out jigs and fixtures and also making up that very costly item, the single component or " 1 off."

It was customary for this sort of work to be done in large firms by a jig borer, and in the smaller firms by the slower and laborious method of marking out, centre punching or scribing and then drilling.

Both methods have one inherent disadvantage—namely, that both require a skilled and, therefore, expensive operator. In the case of the jig borer, great care must be taken on the part of the operator in handling the machine as the screw thread and bearings must always be maintained in perfect condition. The skilled workmanship necessary in constructing the jig borer makes the price for small firms usually prohibitive.

Fig. 123.—*Grampus Nibble Shear.*

The marking out of components or jigs is likewise a skilled and expensive job and, even so, is very slow and with a somewhat doubtful accuracy. The work is handled far more often and cumulative errors are more frequently the rule than the exception.

Knowing this need, partly through their experience in their own tool room, inspection and machine shops and partly through their considerable contacts in the engineering trade, R. K. Dundas, designers, set out to produce a cheap and practical form of jig borer with an accuracy equivalent to anything encountered in normal working. Such accuracy can be described as that of four figure logs or a maximum permissible error of $\pm$ .0005 inch.

The vernier type adjustment gives the most freedom from wear, and at the same time provides a method of measurement which is readily accepted by all engineers.

The accuracy of the Vernijigger is quite independent of the outside applications. In actual fact it is quite possible to use an ordinary hand drill and still maintain accuracy,

Description

The Standard size Vernijigger basic unit for two-dimensional work is manufactured in steel and consists of a fixed arm on which slides a second arm at 90°. On the second arm is a sliding drill bush carrier with provision for slip bushes to take up to a maximum of ½ inch diameter drill. Both the fixed and sliding arms are calibrated in inches to a length of 12 inches in 40ths of an inch and the slides carry vernier cursors. Both arms are made from extremely rigid section hardened on the working surfaces. The verniers are manipulated according to ordinary workshop practice first by sliding roughly to position, then after locking the anchorages, the fine adjustment is made with the knurled screws. Finally the drill bush carrier is locked in position by the pressure plate and knurled screws.

Careful thought has been given to all parts of the design and details to ensure that undue wear will not affect the instrument's accuracy.

The work area covered by the Vernijigger in one setting is approximately 12 inches by 12 inches and the usual procedure is to fix it by clamps or bolts to the work itself or to the table as most convenient, so that the arms movement covers the work area.

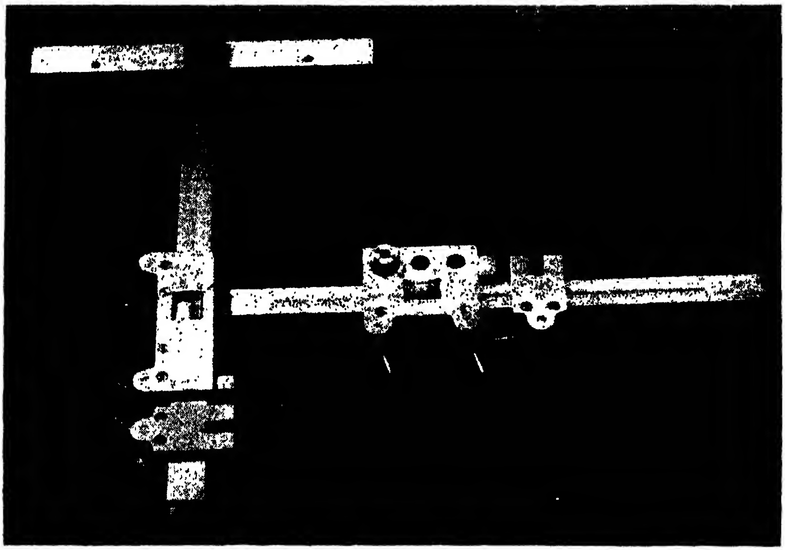


Fig. 124.—The Vernijigger. (R. K. Dundas.)

Procedure

Using as an example the drilling of a piece of flat steel plate such as a drill template the method is as follows :—

(*a*) The assembled Vernijigger is fixed firmly to the edge of the plate or drill table in such a position that when the sliding arm and the drill bush carrier are at as low a reading as possible in each case, the drill bush is over a convenient position for the first hole to be drilled.

(*b*) The locking cams are tightened.

(*c*) A note is made of the reading on the verniers.

(*d*) A drill is selected which must naturally be an accurate fit in the slip bush used.

(*e*) Drill : preferably with a sensitive drill with either the work or the drill head being allowed to float.

(*f*) The position of the next hole to be drilled is now found by unlocking whichever vernier is necessary and moving the drill bush carrier in the required direction and distance required, reading this off on the scales.

(*g*) The workshop practice of reaming holes can be carried out as usual.

Additional Facilities

For marking out a scriber adapter is available and in addition for checking and inspection work an illuminated sighting bush enables accurate positioning of lines, points and edges.

Should a moving head or radial type drill be available an adapter socket can be provided to slip round the drill pillar.

An extremely valuable facility is made possible by the use of two Vernijiggers with special sighting telescopes and cross hairs, for alignment work. Mounted on the surface plate by a protractor head the Vernijigger operates three-dimensionally. Other sizes are available for constant use on small areas or similarly for larger work. Metric scales and instruments for special purposes can be supplied by special arrangement.

Maintenance

Before passing final inspection each Vernijigger is checked for accuracy and a careful operator should have no difficulty in working to limits of $\pm$ .0005 inch. Fine machine oil should be used frequently on the locking clamps and bearing surfaces. The arms should not be forced when hard down to the work. Tightness can be relieved by adjustment of the screw at the end of the arm.

ECONOMY IN THE USE OF SMALL CUTTING TOOLS

By A. E. UPTON

ONE point which is sometimes overlooked is choosing the right tool for the job. It is not only wasting tools but also time to use tools that are " near enough." The first thing to remember is not to order tools with a laconic " They'll be all right." Consider carefully the design of the tool. Is it intended to do just the particular operation you have in mind ? Is high-speed steel or carbon or carbon steel better ? With regard to this, do not jump to the conclusion that high-speed steel tools necessarily give better results than carbon steel. For instance, it has often been found that when working on non-ferrous metals, carbon steel tools produce a much greater output than similar high-speed steel tools and give a better finish.

Further, do not buy on price alone. Buy economically—and this does not mean buy the dearest or the cheapest, but those which obtain the results required. Factors such as delivery and quality are sometimes of far greater importance than the initial cost.

Tool Design and Manufacture

Apropos tool design, there is urgent need for close co-operation between the drawing office and the workshop. The design of certain components all too frequently calls for special tools which are but slightly different from standard. Obtaining these special tools, often required in small quantities only, is at present most difficult, and many firms blankly refuse to accept orders for them. Designers must fully appreciate this difficulty, as very often a minor and unimportant adjustment in design will save a considerable amount of time, expense and worry.

Many concerns make their own tools, and it is possible that economies can be effected in this direction. There is perhaps a tendency for the tool room to undertake the making of tools for which the plant is not entirely suitable, and an outside firm could make the tools better, more quickly, and cheaper. The argument that such a practice may disclose manufacturing secrets can be dismissed as an excuse rather than as a reason.

Before tools are put into use they should be carefully tested. This sometimes reveals faults in manufacture and will be replaced by the maker. If used without testing, the faulty tools would probably be scrapped without comment.

Grinding can be a very wasteful operation, not only in the amount ground off but also because of incorrect cutting angles. In fact, most drill troubles are due to faulty grinding. To obtain the maximum efficiency from a drill, it must be properly ground at the point. It should be ground so that (1) both lips are at the same angle to the axis of the drill (Fig. 125A) ; (2) both lips are of the same length (Fig. 125A) ; (3) correct angle of clearance is given (Fig. 125B), and (4) correct shape of clearance is maintained (Fig. 125C). The importance of grinding cannot be too strongly emphasised, particularly for drills. This should be the job of a skilled operator with proper equipment. and will well repay the expense and trouble taken to ensure that it is being correctly done. It

is also important to ensure that grinding is carried out when necessary. Operators have a tendency to attempt to complete a whole batch of components without grinding, to the detriment of the tools. As a general rule, the drill grinding angles ahown in Figs. 125A to 125C are standard, but experiments on certain classes of work have shown that better results can sometimes be obtained by other methods. For instance, a famous shipbuilding yard found that when drilling armour plate and bullet-proof steel, the output was considerably greater with the lips of the drill flatter than normal practice, and point thinned.

Practical Hints

Further hints based on the actual experience of various firms and their advice are :—

(1) When drilling thin plates, flatten the drill, as it should be drilling the full diameter before the point breaks through.

(2) When drills are ground flatter than standard for any reason the point should be thinned.

(3) When drilling stainless steel or particularly difficult jobs, the drills should be shortened or specially short drills used to effect rigidity and prevent " chatter " which " work hardens " the material being drilled and also tends to break the drill. If restarting on a hole already partly drilled in stainless steel, it is advisable that the drill should be ground to a slightly different angle.

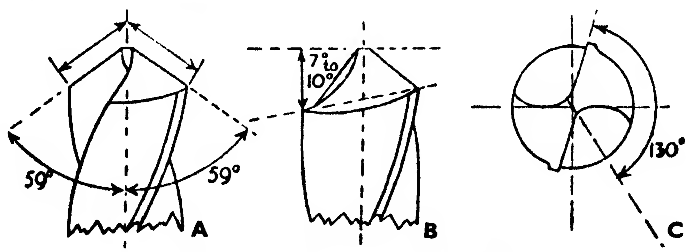


Fig. 125.—*Economical tool grinding.*

(4) When drilling boiler-plates, ships' plates, or " bunched " plates, thin point of drill to help penetration and reduce spring. As is well known, the web of the drill gets thicker the nearer it gets to the shank, so more point thinnning is necessary as the drill is shortened. This should be carefully carried out, equally on each side and not too far up the web.

(5) A sure sign of unequally ground angles, or point out of centre, is when a big chip is coming out of one flute and a small chip out of the other. If this happens, the fault should be at once corrected.

(6) Rounding off the corners of drill lips is sometimes found beneficial on difficult jobs.

(7) Swarf should be removed when drilling very deep holes. If left in the hole it often prevents the coolant from reaching the point and wears away the corners of the drill. To do this, release the feed, keeping the drill revolving, and with the hand-feed mechanism lift the drill out sharply. A simple method of clearing the hole when working on magnetic metals is by using a magnetised steel bar.

(8) It is dangerous to allow work to be held in the hand ; always see that it is tightly clamped to the table. Apart from the danger to the operator, drills are more easily broken.

(9) Use a proper drill drift to drive the drill from the socket, otherwise irreparable damage may be done to the drill or socket or both. Also, when removing drill from the spindle, see that it can drop on something soft, to avoid point being nicked. Before assembling, see that both socket and drill shank are free from dirt or oil, etc., and not damaged ; this ensures a good fit and prevents risk of the tang being twisted off.

(10) Sharp drills do not require as much power to drive as dull drills ; therefore keep drills sharp and reduce the strain and risk of breakage.

(11) Hard spots in the material are sometimes met whilst drilling. When this happens, penetration is often helped by the use of turpentine ; at the same time, reduce feed and speed, and use a " stumpy " drill if possible.

(12) When opening out drilled or cored holes, it is advisable to use three or four fluted drills.

(13) More small drills are broken than worn out when using electric hand braces, and the use of specially short or "stumpy" drills is particularly recommended for such work as drilling aeroplane frames, etc. It will be found that the reduction in breakages more than compensate for the reduced length of drill.

(14) Care should be taken over the coolants used. Make sure that the most suitable is being applied and also that it is reaching the vital part. Quite frequently coolant is seen drenching the work everywhere except just where it should be. Some work is better without a liquid or compound coolant; it should be run dry and cooled with a jet of compressed air.

Coolant

For drilling the following metals, the coolant shown is recommended :—

Cast Iron : Dry or with jet of compressed air.
Mild and Medium Steel : Soluble oil.
Very Hard Steel : Turpentine or kerosene or soluble oil.
Brass or Phosphor-Bronze : Dry or with soluble oil lard oil.
Austenitic Stainless Steel : Soapy water.
Stainless Steel and Iron : Soapy water.
Manganese Steel : Dry or with jet of compressed air.
Aluminium : Soda water or lard oil.
Hard Rubber, Fibre, Bakelite : Dry.

When a lubricant is used, make sure that it reaches the point of the drill. Intermittent cooling, such as dabbing on with a brush, is a most unwise procedure.

Another big factor in tool economy is the human element. All operators are not first-class, some are careless, others careful, and obtaining the best output (as distinct from the greatest) from workpeople is a subject of its own. A greater degree of efficiency, however, can be obtained with some careful thought. For this, almost complete reliance must be placed on charge hands and foremen. On them depends harmony in the shops, and they must, therefore, know their job and have the respect and good will of the staff. These two characteristics are not always found together. Further, they must be able to train operators, so that they can avoid troubles and consequent waste. Operators should also be encouraged to suggest methods of improvement themselves.

Macrome Tool Toughening

This treatment can be applied to all types of drills, taps, milling cutters, reamers, slitting saws, screwing dies, hacksaws, turning tools, etc., with equally beneficial results. No technical details are available concerning the process, but it is pointed out that it is not a form of case-hardening or deposition, and has no connection with chromium plating. It is claimed that after its application considerably higher speeds and feeds than normal can be used.

The treatment is applied when tools are normally regarded as ready for use. The whole bulk of the metal is toughened, so that the benefits are not lost, however many times the tools are reground. The effect of the treatment is to give cutting tools an added active resistance to the damaging stresses to which they are subjected. Tests have been carried out by firms both large and small to determine what increased life the treatment actually gave to tools. These tests were usually of the firms' standard tools, untreated and treated, so that fair comparisons would be made. A few of the results are shown in Table XVII, provided by a well-known Midland aeroplane factory :—

TABLE XVII

Drills Used	Usual Make. 7/64" diam. Untreated	Usual Make. 7/64" diam. Treated
No. of Drills Tested	12	12
No. of Holes Drilled	587	2,148
No. of Regrinds	29	30
Average No. of Holes per Regrind	20.5	70.5

Several tests have been made with screwing dies, one of which, at one of the oldest and most famous aeroplane factories, resulted as follows :—A treated set completed 7,467 components before requiring regrinding, whereas the normal output was about 1,000. An important firm engaged in shell manufacture tested the effect of the treatment on various tools, the results of some of these being given in Table XVIII.

TABLE XVIII

Results of Tool Toughening for Shell Manufacture

Turning Tools		Radius Boring Tools		Cutters	
Average output per tool		Average output per tool		Average output per tool	
Treated	Untreated	Treated	Untreated	Treated	Untreated
2,743	525	400	188	240	138

Many examples on the lines of the foregoing are claimed, as these are constantly being compiled. It is the advantages of such a treatment that are important. The first obvious point is that with such a considerably increased output per tool not nearly so many tools would be required. This would reduce by a big amount the tool costs, but even more important is the time-saving. With tools doing much more work between grinds and the possibility of increased feeds and speeds, there is a great deal of time saved in grinding, setting up, handling, and so on. This speeds up ouput, and where production is on a very large scale it is possible that labour and machines would be economised. With the present acute shortage of both of these, this is a point not to be overlooked. A further advantage is that firms using tools can virtually double their stocks by having their tools toughened by this treatment. As previously mentioned the treatment is applied after the usual heat treatments and does not distort, alter size or affect the heat structure of the article. Tools which have been used and reground can also be treated and show equally good improvements.

Part III

MANUFACTURE AND ASSEMBLY OF WOODEN AIRCRAFT

THE MILES MASTER

A TWO-SEATER low-wing cantilever monoplane, the Miles Master is of wood throughout. The fuselage is of semi-monocoque type and the wings are built round two box-type spars. A characteristic feature of the aircraft is the wing centre section of " inverted gull " formation which houses the fuel tanks and the undercarriage in its retracted position. Plywood skin covering is used for fuselage and main planes. Hydraulically-operated split trailing edge flaps are fitted, extending across the centre section beneath the fuselage. In the main the Master is conventional in construction, although there are several outstandingly neat points in design. Certain unusual features, in particular the inverted gull-shaped centre section of the wing, which might be expected to cause difficulties in manufacture, are produced with a minimum of trouble.

Wing Spars

Two box spars form the basis of the wing, which is made up of a centre section and two outer planes, and both front and rear centre-section spars follow the gull form of the wing, as well as tapering between their front and rear faces. The front spar is considerably larger than the rear one, but both are made in the same way. The taper, when the two spars are viewed end on, is such that the front spar is deeper on its rear face than the rear spar on its front face.

Large screw presses are used for glueing the spruce laminations for the spar booms. A heavy top beam, shaped to the gull form required in the spar, presses the lamination on to a similar-shaped lower beam. Between twelve and eighteen spruce planks are glued for the full length of the booms, while for about a quarter of the length at each end some dozen shorter plank sections are added. The planks for the rear spar are fewer and narrower.

Temperature and humidity affect the period required for the glue to dry, both for the boom laminations and more particularly for the construction of the spar. In hot, dry weather eight hours would suffice, though the booms are usually left in the press for about twenty-four hours. On removal they are taken to the wood mill for machining, which includes planing of faces, finishing of ends, and profiling of edges.

A jig, the principle of which is standardised for all similar components, is used for the building up of centre-section spars. A heavily built table with a thick multiply top cover has a number of blocks screwed to it for locating the spar members. The upper and lower booms are first placed in position and held firmly against the outside location blocks by wedges tapped in between their outside edges and the blocks.

Finished soldiers or internal members made in the wood mill to template are placed in position between the booms. If necessary the surfaces are touched up with planes, after which the first skin may be applied.

The skins are received from Saro Laminated Wood Products, Ltd., in shaped form but about ½ inch oversize all round. A full-size sheet-metal drilling template is placed on the plywood skin and all holes are drilled before glueing. At the same time the positions of the rib blocks are marked on the skin in pencil from the template. Apart from the holes for screws, each front spar skin has four, and each rear spar skin three, location holes which are used to position the spar in the jig when it is turned over, and later in the drilling jig for end fittings. Pegs through the holes also locate the second skin and the drilling plates. A solid block, drilled before assembly, spaces and supports the skins at the location holes. All jigs into which the spars are placed have steel blocks and pins corresponding with the holes. This system is also used for outer wing spars, three holes being used in each spar.

Glueing Operations

Glueing is not carried out at a temperature of less than 55° F., and of course a temperature-controlled air-conditioned shop would be desirable for the work. A cold-setting casein glue to Specification 3 V.2 is used, supplied by Lactocol, Ltd., and

Fig. 126.—A Front Centre-section Box Spar clamped in its jig while the glue for the skin sets.

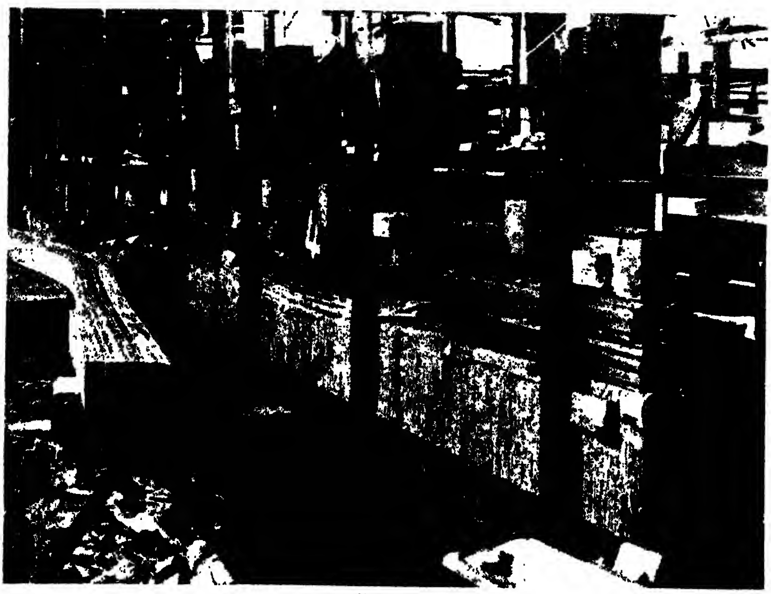


Fig. 127.—Glueing spruce laminations for the main spar booms at the gull-wing centre section.

brushed on to both booms and soldiers and on to the skin surface, which is marked out in pencil to receive it. The glue sinks into the wood quite rapidly and the skin is applied at once. Sheets of newspaper, followed by a 1-inch multi-ply top cover, are placed over the skin, these being held down by heavy cross-pieces comprising two lengths of angle iron bolted back to back. Large swing bolts which hinge up from the sides of the table are used to " nip down " the metal cross-pieces.

When the glue is set the partly finished spar is turned over in the jig and all internal surfaces are treated with an undercoat of primer to Specification X.16 and a finisher coat of D.T.D.63A for protection against damp and rot.

A second inspection follows the internal proofing, the first being of the assembly components before glueing. The same glueing and clamping procedure is then followed for the second skin as for the first.

The screws which secure the plywood webs to the spar members are inserted while these are clamped together in position, and while the glue is still wet. Owing to the length of the spar the glue is usually beginning to set by the time the operation is completed.

Completed main spars are sent back to the wood mill for cleaning up of edges and ends. Undercoating to Specification X.16 is applied to the spar ends, and a coat of D.T.D. 63A white paint is put over it. In this way the grain is closed and any tendency to split is minimised.

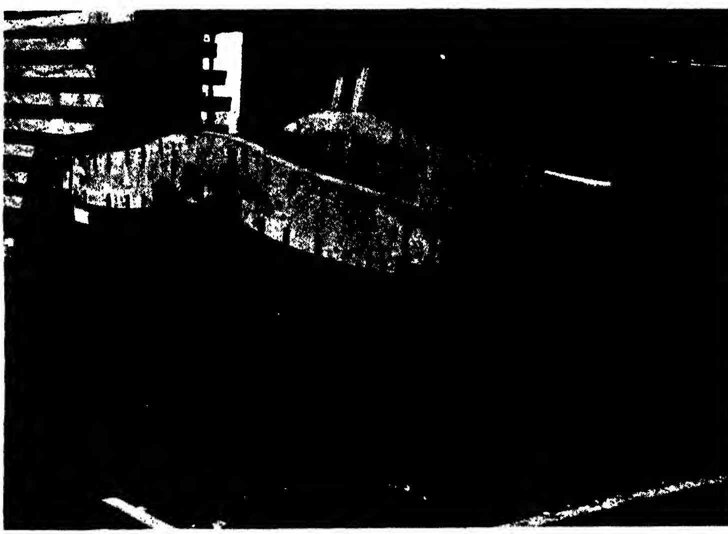


Fig. 128.—*Centre Section Spars with their attachment fittings are checked in a large jig.*

The production of the rear spars is carried out in a similar manner, but the plywood skins are of $\frac{1}{8}$ inch thickness, instead of $\frac{1}{4}$ inch as for the front spar. The skins for both spars are drilled from templates, five at a time. Small electric hand drills are used for the operation.

When the completed spars are returned from the wood mill the rib blocks and other small pieces are glued and screwed on, positions having been marked out from the template, which also enables a check of the spar contour to be made.

The blocks for the ribs placed at top and bottom of the inside spar faces are of spruce, while the packing pieces at the point of attachment of the spar plates are of $\frac{1}{4}$ inch multi-plywood.

Finished spars are stored horizontally in racks and weigh, without fittings, 155 lbs. and 62 lbs. for front and rear spars respectively.

Drilling Spars for End Fittings

An interesting scheme has been evolved for drilling main spars for end fittings. It requires two men to handle a front spar and some care to place them in the large drilling jigs.

These comprise a frame made from rolled-steel sections, carrying baseplates for the support of the spar and having pins for its accurate location which engage the holes previously drilled in the webs for this purpose. Vertical pillars are also mounted in these plates, extending up to a height above the level of the top of the spar when this is in position for drilling.

At the top these pillars are reduced in size as seen in Fig. 128, and this smaller diameter, in conjunction with the shoulder so formed, serves as a positive means of location for the removable top drill plates. These are cast of aluminium to reduce the weight which must be handled and have hardened steel bushes for the drills and location pillars.

For handling the jigs, a long roller conveyor has been installed across the front of a large Archdale radial drill. The operator can position the spar and its jig without difficulty under the drill, while two other men place another spar in its jig at the near end of the conveyor. Finished spars are pushed past the drill to the far end of the conveyor for unloading. Spars are drilled in batches, the drill being used in the intervals between these for other wing components.

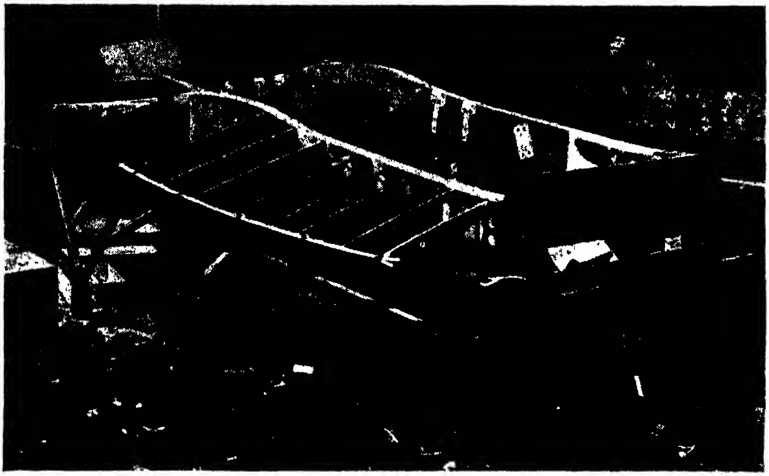


Fig. 129.—Assembling the wing centre section.

A heavy jig, similar to the main centre-section jigs, is used for checking the attachment of end fittings, no tolerance being allowed. A shrinkage allowance of 0.030 inch is, however, made on all spars at an early stage in production. The main wing attachment fittings are bolted to the spars, and steel plates, placed between fitting and spar face, give additional strength. Bolts with Simmonds nuts on each end are used. This method of attachment and the plates are similar to those used for the main undercarriage casting.

Bolt holes passing through the spars have steel distance tubes inserted to prevent slacking of the bolts due to shrinkage of the wood, and the attachment points of all fittings to the skins correspond with internal blocks which give the required strength and rigidity.

Centre Sections

The building up of the centre sections is quite a simple process. Two finished spars, complete with fittings, are located in the jig by three main attachment lugs, and two heavy castings are then bolted between the spars to give the correct spacing and rigidity. These castings may be regarded as dummy fuselage sides. Inter-spar ribs

are brought from stores ready for attachment add are located from their respective blocks on the spars. A separate portion of the jig rising from the floor is of ingenious design and supports and locates the rear ends of the trailing edge ribs.

Generally speaking, the main ribs are of similar construction to the spars. Spruce booms are joined by girders and a thin plywood-skin is glued on each side. The ribs are screwed to the blocks on the spars. Plywood gusset strips are glued and screwed to the posts on the spars when assembling the ribs to ensure a good joint and to allow for small differences in spar centres. A cap of spruce round the nose ribs gives a good glued joint between ribs and skin on covering of the wing.

As the centre section houses the fuel tanks and the landing wheels, only the two outside main ribs are complete, the others being cut away for the fairing (part plywood, part metal) around the wheel and to give room for the fuel tank. Blocks lined with rubber, and metal brackets, previously attached to the main spar, support the tank, which is installed at a much later stage during final assembly.

Fig. 130.—A general view in the wing centre-section department.

Rib Construction

Leading edge ribs are attached to the centre section while in its main jig. These are made from ½ inch multi-plywood with spruce capping to give a good glued joint with the skin. The outer centre-section nose ribs each have a single multi-plywood bracing member and are joined by a transverse strip on the underside. The ribs are attached to the front spar chiefly by spruce blocks, but those close into the fuselage have metal brackets.

Ribs for the trailing edge are in effect small replicas of the main spars and ribs. Spruce booms with spruce bracing members form the framework, and thin plywood-skins are glued on each side. They are screwed to blocks on the rear main wing spar and are braced at the rear ends by a spruce beading which follows the curvature of the wing and centre section flaps. Part of the underside of the ribs is cut away to house the flaps, which are of the split type.

On completion of the framework, the top skin is applied while the centre section is still in the jig. This is in large sheets and the leading-edge skins on each side of the fuselage are made from single curved plywood sheets. In all there are six skin panels of 2 mm. plywood on the top surface and leading edge. The under surface and trailing edge skins are 1½ mm. plywood. The skins are screwed and glued to the framework. At the junction of two skin panels the edges are bevelled and overlapped and a plywood strip is tacked over the joint while the glue is setting. It is almost impossible to detect the joints between the skin sections on either wings or fuselage.

An overhead crane lifts the partly finished centre sections from their jigs, after which they are placed on trestles for conveyance to the dope shop. Centre sections can be turned over in this mobile trestle for ease of doping both inside and outside surfaces, but the centre section is normally carried on its side with padded supports to steady it.

After painting, the centre section is returned to the assembly shop and supported upside down on trestles while the remaining fittings, wires, pipe lines and controls are installed. Wiring is carried in very light plastic conduits made by British Celanese, Ltd., and all metal parts are bonded by thin tinned copper ribbon which is tacked along the main frame members.

The fittings for the undercarriage and controls are, in the main, magnesium castings, and single large magnesium castings bolted to the front main spar carry the undercarriage leg on each side. The control rods and the flap and aileron hinges have ball-bearing joints.

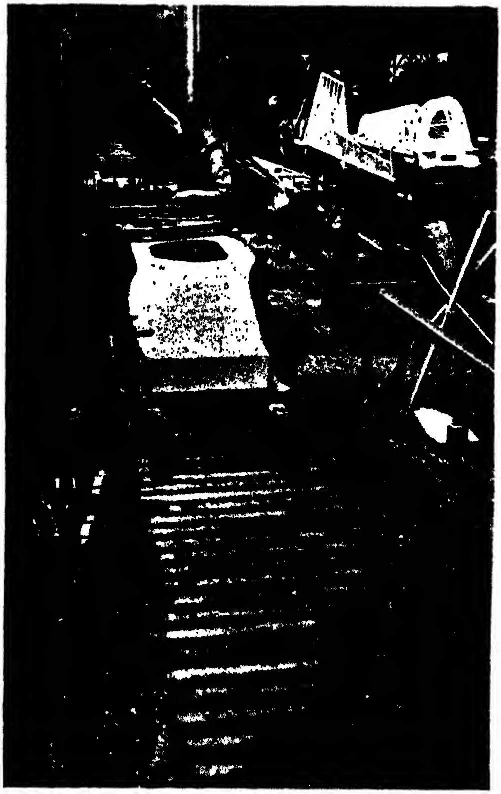


Fig. 131.—*Centre-section spars are drilled for end fittings in special jigs. Owing to the weight of jig and spar, a roller-conveyor is used for handling purposes.*

The last operation on the centre section is the application of the underside skin. At present the wing centre-section shop, which opens at one side on to the main wing and spar sections and on the other into the main assembly bay, is rather cramped for space. Finished centre sections are collected at the main assembly end, and when and where possible the landing wheels and legs are attached to their fittings. From the very first stage of assembly the machines are supported in front on their own legs and wheels.

Fuselages

Rather unusual jigs are used for the master fuselage, and the methods bear a marked similarity to those employed for certain all-metal bombers, in particular the Battle. A cantilever jig built round a single tubular support which passes down the centre of the fuselage is threaded with fuselage frames. Longerons are located and attached to the frames and then the skin is applied. Hinged and collapsible portions of the jig permit withdrawal of the finished fuselage shell.

The jigs, of which there are eight in all, are built in pairs about very sturdy central supports, the two cantilever tubes projecting out at opposite sides and balancing each other. Although the jigs are cantilever type, a support is arranged for the outer extremity of the boom during assembly to increase the rigidity. This support is triangular and is hinged from the floor. A rack and table which holds all frames and fittings, blocks, glue, etc., for one fuselage at a time, and carries a complete list of parts, must be regarded as a component of each jig.

To reduce the amount of work, other than actual assembly on the jigs, some of the fuselage frames which need extra strengthening or fittings go to the jigs as complete grouped units. There are four such units, which are threaded over the jig boom with the simpler frames between. The various hinged and detachable sections of the jig are then located.

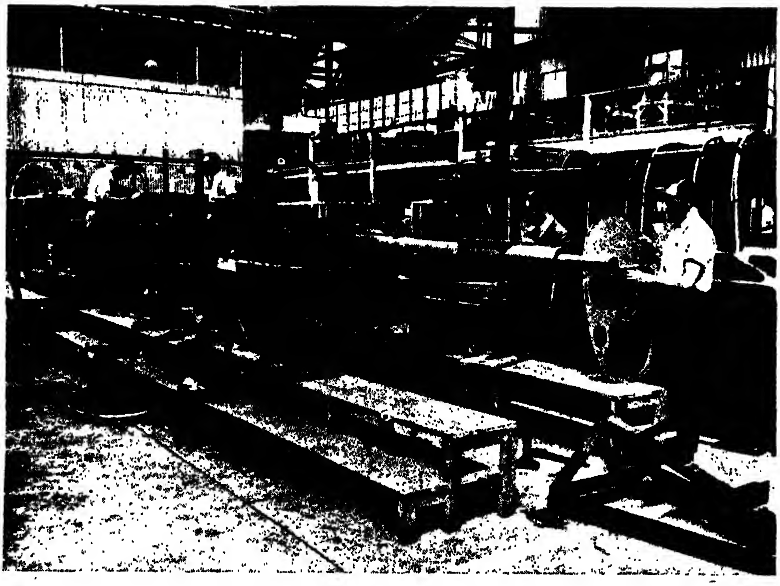


Fig. 132.—Threading fuselage frames on to the cantilever jig, at the beginning of fuselage construction.

Fuselage Frames

Fuselage frames, of which there are in all seventeen, are of birch multi-plywood. The required form is obtained by profiling them to template in the wood mill on Wadkin routing machines. They are located in the jigs by bolts and wing nuts.

Attachment of the four main spruce longerons is commenced as soon as the frames are in position. These longerons are complete with their end fittings for attachment to the spars and the top two are made in two sections with scarf joints and strengthening plates at these joints.

Notches between $\frac{1}{8}$ inch and $\frac{1}{4}$ inch oversize are cut in the frames to take the longerons. The slack is taken up by small mahogany wedges, which are tapped into position on each side of a longeron and serve to centralise it and to stiffen the joint. All the wedges for one longeron are first placed temporarily and then removed for glueing all at the

same time. Casein glue is used for this purpose. Small screw clamps are used to grip the member of each glued joint. The frames all have a spruce capping between the skin and multi-plywood edge.

Light stringers of tapered section support the fairing behind the cockpit and the side and under panels. The frames also have notches of correct size and shape for these stringers and the attachment is by glueing and tacking.

Of the four frame units, the front one is the most substantial, in that it takes the fittings for the engine mountings and is attached to the front main spar. It is composed of three pairs of heavy multi-plywood frames joined by spruce blocks. A plywood skin is also placed over its edges. It carries the main attachment fittings of the centre section to the fuselage, the front centre section spar being raised into a slot in the fuselage.

The second frame unit falls between the two cockpits and is strengthened to carry the instrument panel. The third embodies the rear cockpit floor. The next frames rearwards are single, although they are the first complete frames, those forward being cut away for the cockpit enclosure. A compartment with plywood sides and floor is arranged between two of them to house the battery. All the frames are cut out at various points for lightness. The last two frames are strengthened and braced up to support the tail surface and tail wheel mounting and blocks for the lifting tube are added in the jig.

The stern post may be regarded as the last frame, in that the ends of the longerons and stringers are attached to it in the same way as for a frame member and at its base it follows the deep oval form of the rear end of the fuselage.

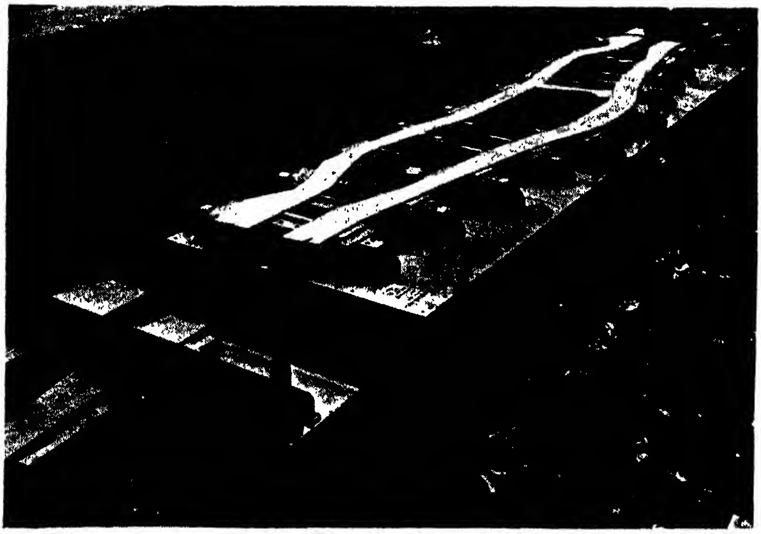


Fig. 133.—*After machining, the spar booms are placed in special jigs with the web members for glueing on of spruce sections.*

In keeping with all other spars, the stern post is built up round two spruce booms joined up by spruce cross-members and faced on both sides by plywood sheets glued and screwed to the framework.

Before the skin is applied several details must receive attention. Beneath the rear end of the fuselage is a diamond-shaped inspection hole, which gives access to the flying controls and, if necessary, entry to the fuselage shell. Ribs and bracing members and the framework for this trap must be fitted, bonding strips tacked to the two lower longerons. All fittings, bolts, etc., are painted with Duralac, prior to assembly.

Applying the Skin

The skin is applied in large panels of various thicknesses and the joints are bevelled and overlap. While the glue at the joints is setting, plywood strips, previously prepared, are tacked tightly over the edges. Skin sections and gauges are as follows :—

Rear bottom panel	2½ mm.
Mid-bottom panel	2½ mm.
Tail sides	2½ mm.
Rear sides	2½ mm.
Mid-sides	2 mm.
Centre-section sides	⅛ inch.
Reinforced front side panels	⅛ inch.
One-piece top cover	2 mm.
Top decking	1½ mm.

The various panels are prepared in advance, cut to size and drilled. They are then stored in lettered shelves near the job. One-piece curved top panels are held tightly round a forming jig while damp and are left for about twenty-four hours to assume the required shape.

The fuselage framework is submitted to the firm's and to A.I.D. inspection before the skin is fitted. After skinning and withdrawal from the main jig, the first coat of red dope is applied as soon as possible and the fuselage can then be checked for rigging prior to installation of fittings, inspection doors, etc. Rigging is checked from readings taken on a tailplane gauge and from the bolts for the engine attachment fittings. The plumb-bob and string methods are employed and a 10-foot plate is used on top for the inclinometer.

These rigging checks are purely precautionary, as no discrepancies are to be expected from such a jig-built fuselage and, in the unlikely event of inaccuracy being found, no adjustment could very well be made, so the fuselage would probably be scrapped.

To withdraw a finished fuselage from its jig the hinged and detachable portions must first be removed and all attachments released. Stages of this procedure are :—

(1) Remove detachable portion of jig stretching from rear cockpit to accumulator stowage.
(2) Remove dummy centre-section bolts and take out dummy spars (these are heavy castings which are lowered out of the spar slots).
(3) Release all toggle points and locking pins and turn inwards.
(4) Remove tailplane and fin location sections of jig.
(5) Release bolts and pins on rear pivot block on main jig.
(6) Jack-up boom until it clears and drop back main end support.
(7) Remove jack, allowing boom to take its own weight. (Balanced by opposite jig.)
(8) Draw off fuselage.

During withdrawal a small tramway running on girder rails supports the front end of the fuselage. A single track also supports and steadies the largest detachable portion of the jig behind the cockpit.

The fuselage can be turned through about 120° on either side of the vertical, the stern post preventing complete revolution.

A number of operations must be completed before the fuselage from the jig is ready for the final assembly lines. For this it is supported on wooden trestles.

Drilling Operations

In the first place, all internal blocks must be fitted and at the same time Simmonds anchor nuts are fixed for the attachment of the metal wing fillet. A large wooden drilling jig is used for the holes, and the nuts are positioned from them. Instructions are printed on the jig, which is reversible for use on port or starboard side. The jig locates from a flange at its top which bears on the cockpit edge. The flange and a curved stiffening section are detachable and can be fitted to either side of the jig. Holes in the jig are reinforced with small sections of wood and carry steel bushes. An inspection hole for the ballast stowage is also cut at this stage.

Assembly proceeds with the fitting of a door for the accumulator department, the drilling of holes for attachment of the tailplane fillets and fixing of anchor nuts behind these holes. A hole for the tail wheel and its lug is also cut out. A recess is made for the door giving access to the flying controls and the panel for the flap well is cut out Stiffeners are fitted around the identification lights below the fuselage and a frame for the door of the first-aid compartment is added. There then remains to be fitted an inspection door on the side of the fuselage for the rear controls.

A reinforced plywood structure forms the drilling jig for the tailplane fillets and like that for the main wing fillets, carries strengthening blocks around the holes which have metal bushes. Jigs for drilling attachment bolt holes for the tail units and for the engine mounting fittings are of heavy steel construction and a large plan jig is used for all holes on the cockpit decking and plan bracing.

The cockpit section receives an undercoat of grey paint and the fittings are assembled wet with Duralac. Distance tubes, also painted with Duralac, are inserted for the bolt holes of the main spar and engine mounting fittings.

Spars for the outer wings are made in the same manner as those for the centre section, although they are considerably lighter. The wooden jigs for them are built on the same principle but are somewhat simpler. All the inter-boom members or soldiers are evenly spaced and upright and there is pronounced taper towards the tip both in shape of boom and shape of spar. The booms are pressed against the inside blocks which locate the soldiers by boards shaped to spar form, these in turn being pressed up by wooden levers on eccentric pivots. Certain adjustable blocks on the jig are held by bolts through slots which permit limited movement.

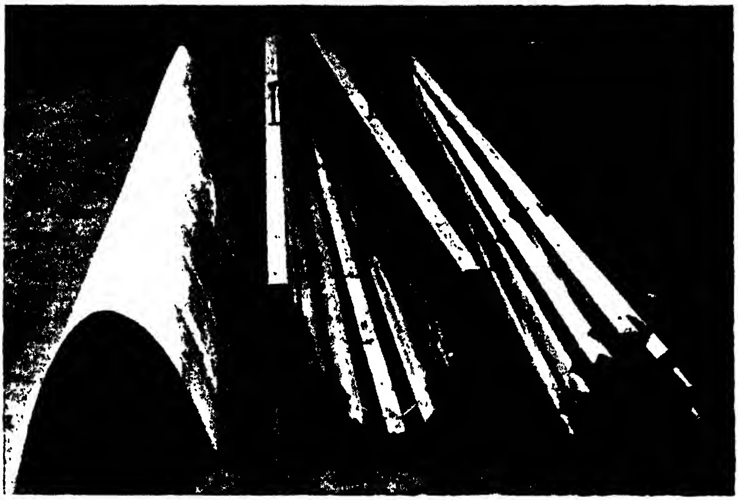


Fig. 134.—The jig in which the leading-edge skin is formed.

Procedure for building up the spar is identical with that of the centre section. The soldiers are glued to the booms, inspected and the top skin applied, glued and screwed. The skins which are already shaped and drilled are located in the jigs by three metal pegs. Holes are cut in the rear spar for the aileron differential gear. Instead of girder cross-pieces and heavy screw attachments the skin is held down by ash cross-pieces and wedges. The cross-pieces are kept in a box at the end of the jig, and when in use are passed through slots in a series of wooden uprights on each side of the jig. After removal from the jigs, spars are sent to the wood mill for finishing. This entails spindling the edges and cutting the ends to length.

Holes for the attachment fittings of the main planes are drilled on the Archdale machine described previously, and mahogany blocks are used to correct for the taper of the spar faces at the points of attachment of the fittings.

Outer wing spar jigs and those for certain other spars and small units are pivoted at each end and can be rotated. In this way the top side of the jig can be used for assembling one spar while the glue on another is drying on the underside. This halves the number of jigs required, and, a matter of equal importance, reduces the space occupied by those which are necessary.

Before the skin is applied to the spar, the interior surfaces are treated with white paint; then the second skin is applied in the manner described previously for other

spars. Finally the spars are marked out for the rib blocks, distance pieces and blocks for fittings and these are glued and screwed on. To facilitate the fitting of the large number of similar but not interchangeable blocks, each one is numbered to correspond with numbers beside the slots on the marking-out template.

The greater part of the detail work on the outer wings is completed before the components are placed in the main assembly jig. When completed, the front and rear spars are taken to simple jigs carried on tubular pedestals, for the building up of the trailing edge and nose ribs. The spars are located in these jigs by pegs placed in the three holes to which reference has already been made, and the ribs are attached by bolts and wing nuts. The ribs are screwed to their blocks and, in the case of those ribs which are lined up with a straight edge, metal bands are employed for support while the glue sets. Nose and trailing edge ribs are produced in the general rib shop, and after inspection are placed in the store from which they are issued as required.

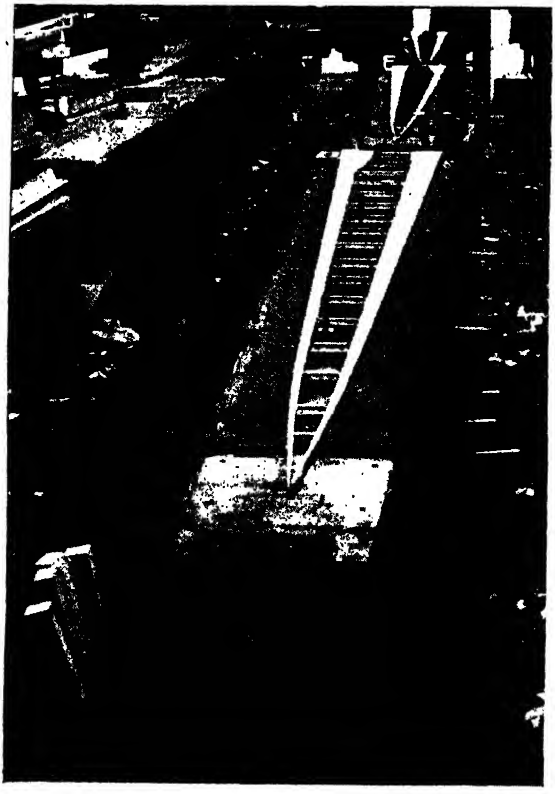


Fig. 135.—*An assembly jig for the main spar.*

The main wing jigs take both port and starboard wings, dummy centre-section fittings being placed on opposite sides of a strong central framework for location of the spar root. The spar tips are also supported. As with other units, the inter-spar ribs are located and screwed to their blocks and the lower skin is applied.

Wing ribs are made in three sections, namely, leading edge, inter-spar and trailing edge. Spruce is employed for both booms and bracing members to which plywood " biscuits " are glued to make the joints.

Each rib is attached to the wing spar by being glued and screwed to the external spar stiffener. Ribs are made to the full depth of the spars, so presenting, after assembly, a flush surface for the application of the plywood covering which gives lateral stability

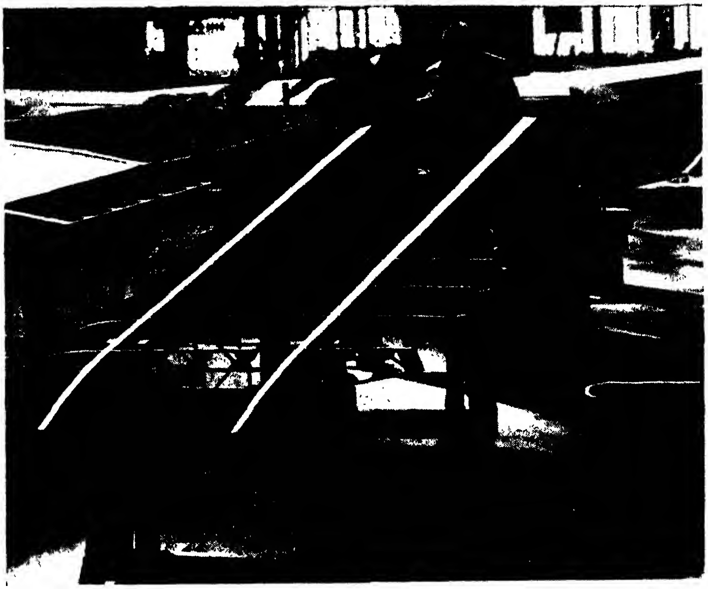


Fig. 136.—The first stage jig, ribs and underside skin.

for the ribs. They are lettered in order of position from K to P, omitting O. The whole unit is then taken to the dope shop and painted on the inside.

Fittings, controls, wiring and bonding strips are installed in the wing after interior painting. Magnesium castings are used for the controls, and the conduits for the wires to the navigation lights, etc., are of synthetic material. The hydraulic jacks for flap operation and the hinges for the flaps themselves are also fitted. The second skin is then attached.

After both skins have been applied and the wing has been returned from the dope shop, panels are cut out for the landing lamps and flare doors. All inspection doors for

Fig. 137.—The second stage wing assembly jig.

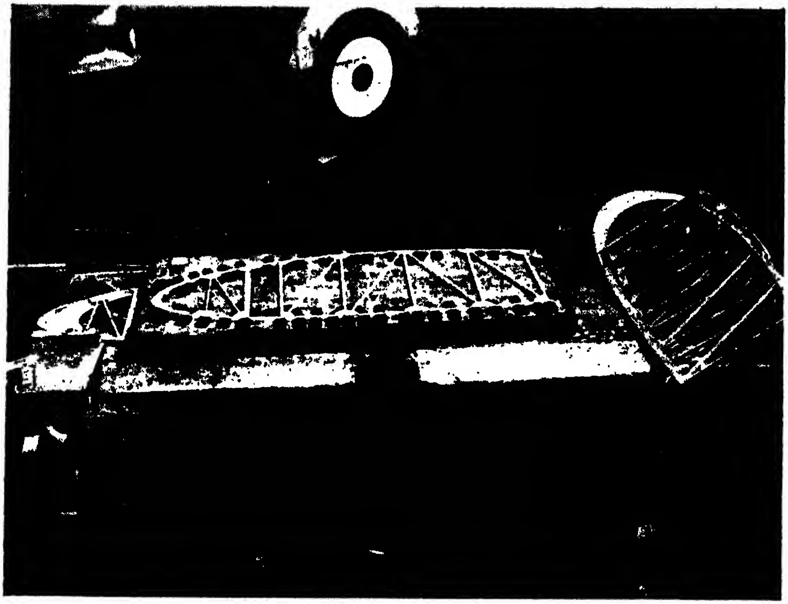


Fig. 138.—Nose ribs and interspar ribs are assembled as single units and later cut into two sections.

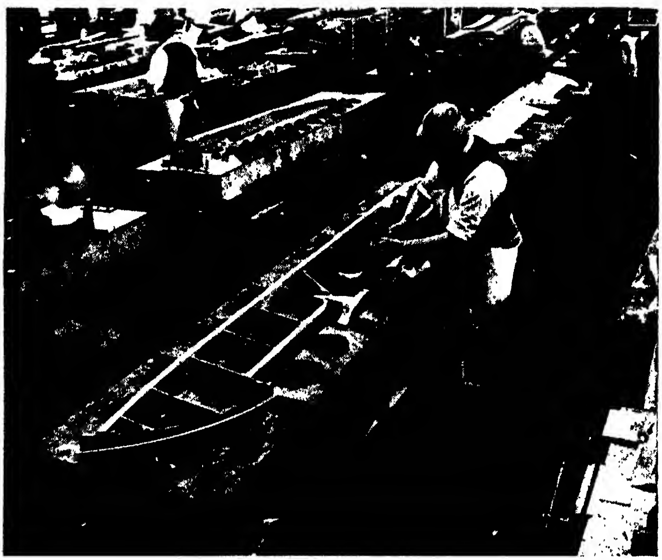


Fig. 139.—One-piece elevators being built up on revolving jigs.

controls, fittings and fuses are of light alloy throughout the aircraft, and in the main are hinged at one side and secured by screws. There are three drain holes in the port wing and two in the starboard wing.

The wing tips, which are small metal units, are fixed by screws to brackets on the outside wing rib, and embody faired-in wing tip navigation lights. The tips are interchangeable between different machines.

A number of small units are produced in a balcony overlooking the fuselage assembly shop. These include the various spruce-capped frame units which have already been described, the front and rear cockpit floors, wheel wells for the undercarriage when in the retracted position, stern posts and certain rib members. The shaping of large fuselage panels is also carried out in this section. For cutting out small parts a small Walker Turner bandsaw is employed.

Fig. 140.—*Building up trailing and leading edges on outer wing spars before these are passed to the main wing assembly shop.*

Tail and Control Surfaces

All smaller units, such as flaps, ailerons and rudders, are made in one bay adjacent to the main wing section, and the methods employed are much the same for all. The jigs are built up on heavy wooden tables supported at each end on pivots carried on tubular supports. As in the case of spars, this scheme enables one side of the jig to be used for assembly, while the glue on another completed unit is setting on the underside.

Centre-section flaps follow the gull contour of the wing and are built around a single-curved spruce spar placed just forward of the centre line. Outer flaps are of similar construction, but are flat and regular in shape. A front and rear rail braces the tips of the solid spruce formers and one-piece plywood skins cover the upper and lower surfaces. The whole unit is roughly triangular in section. Hinge fittings are carried on blocks attached to both skins and to the spar. Hydraulic jacks operate the centre-section flaps, which are connected by sliding universal joints to the outer flaps. The control brackets and hinges for these units are magnesium castings, as are the majority of such components throughout the aircraft.

A single spruce and plywood box spar forms the nucleus of both ailerons and elevators and the ribs or formers in each case have spruce booms and stiffeners with plywood webs. They have a stressed plywood covering, and the elevator carries a small metal trimming tab turning on spigots, held in magnesium castings attached to the ribs.

The rudder is also built up on a revolving jig, the weight being distributed evenly on each side of the axis. This irregular unit, which is of interest as being the only fabric-covered surface, is built round a single box spar. In this case, also, the ribs have

spruce booms and plywood webs. The tips of the ribs are attached to a laminated spruce bend, which is cut away for fitment of the trimming tab. Multi-plywood form ribs are attached to the front surface of the spar where it faces the stern post.

Trimming Tabs

The trimming tabs on both rudder and elevators can be adjusted in flight. These tabs are of light alloy sheet and are carried on adjustable spigots in magnesium alloy castings attached to the ribs. The tailplane is of conventional design and is built about two spruce and plywood box spars in a similar manner to the main outer plane. It is attached to the fuselage frames by flat steel plates with flanged edges. The tail fin has a cantilever spar attached to the third fuselage frame from the stern post. The spar is parallel with the fin leading edge, and the ribs are attached to the spar and are also bolted to the stern post. This unit is plywood covered and has a one-piece leading edge. The main bracing member is vertical and comprises the standardised spruce and plywood member. Circular holes are cut out of the plywood for lightening purposes. When one skin has been applied the unit is carried in a cradle lined with felt. Simmonds anchor nuts are attached for screwing on the fillets and fairings at a later stage. After internal painting all units of the empennage are bonded with tinned copper ribbon, tacked to the main members.

Fig. 141.—A partly-finished rudder, showing details of its construction.

General Assembly

As soon as fuselages are released, after inspection and doping, they are placed on trestles located between the fuselage shop and assembly lines. Complete instrument panels, which are made up and partly wired in another department, are installed, and, where possible, connected up.

Certain other fittings and small units can also be added at this stage. These include clips and conduits for wiring to be added later, main engine-mounting lugs and fittings; castings and brackets for engine controls. Tail wheel assemblies and underside identification lights are also fitted.

Final assembly is divided into some seven main stages. First, the fuselage and wing centre sections are assembled and bolted together. Attachment brackets are carried on the main bottom longerons and the two spars fit into slots in the fuselage. When in position, the lower faces of the spars are flush with the underside of the fuselage. The strengthened first frame unit of the fuselage which carries the engine mounting

lugs has steel-bushed holes passing longitudinally through it. The slot for the front spar is between the frames of this unit. Long bolts pass right through the three frames of the unit and through the spar. At the rear end these bolts pass through the longeron fittings and in front to the lower bracket of the engine mounting fitting. Engine load is therefore taken directly by both longerons and main wing spar.

It will be remembered that the landing wheels and legs have been fitted to the wing centre section. From stage two of the final assembly onwards these wheels, placed in boxes to prevent movement, support the front of the fuselage. The rear end is placed on a trestle. The legs are semi-cantilever and are locked in the down position by a sliding sleeve. They are hydraulically operated.

Fig. 142.—All hydraulic equipment is mounted in the cockpit floor while this is on the bench.

While the fuselage is supported on wheels and trestle, the tail fin and crash frame are attached. The crash frame is a heavy section magnesium alloy half-hoop bolted to the cockpit deck between pilot and pupil. In the event of the aircraft turning over it is strong enough to prevent the collapse of the enclosure.

More pipe lines are added at stage two and the undercarriage mechanism is completed. A reinforced non-skid strip on the top of the wing for entry into the cockpits is also attached at or just before this stage.

Assembly continues with the addition of the tailplane and control rods. These rods are of the push-pull type and are made from light alloy tubes. They work between rubber-covered ball races. Levers and brackets used in this connection are magnesium

alloy castings with ball bearings pressed into the ends. Control column, rudder bar, brakes, etc., are built as a unit in the shops.

Final assembly is greatly simplified by mounting the entire hydraulic system in the front cockpit floor. This is thus assembled in position as an almost finished unit. The hydraulic units are built into the floor structure on the bench when the interior is most easily accessible.

After the fitting of floors and seats comes the installation of engine controls and that of the engine itself. On the Master, the throttle, mixture control, airscrew control, trimming tab levers and cable drums, etc., are all grouped on a single quadrant. The engine is received as a complete unit in its mounting with the majority of pipe lines and control rods connected to unions on the bulkhead. The engine mounting is of steel tubes with forgings at the joints. In the first place, the Rolls-Royce Kestrel XXX unit is sent to another contractor in the bare state. This firm then completes the mounting and preliminary installation. Phillips and Powis therefore have the task of installation reduced to that of bolting up the mounting at the four attachment points on the fuselage behind the bulkhead and connecting up the remaining services. The mounting lugs

Fig. 143.—*The control column and rudder bar unit is taken in semi-complete form to the main assembly lines.*

for the engine unit are two horizontal flat steel plates on each side at the top of the strengthened first fuselage frame and forged steel trunnions for the downward angle.

The oil tank is mounted high up behind the bulkhead. It is of welded alloy construction and is held down by straps. The filter is integral with the tank, which holds seven gallons of oil.

By the time stage six of the assembly is reached all these units have been assembled and the machine is ready for the outer wings and radiator. The Serck or Marston radiator is housed in a neat duct well back and below the front cockpit and is carried on a framework of welded steel tubes with three-point attachment to the wing centre section. It may be remembered that on the prototype Kestrel trainer the radiator was mounted well forward under the nose. It comprises two separate cylindrical coolant units with an oil cooler of similar shape between and slightly below. A flap controls the outlet of air at the rear of the duct.

Attachment of main planes is effected by two hollow bolts that pass through the fittings on the front spars of the outer wing and centre section. Two more bolts are used for the rear spar fittings, these being small and solid. Flat light alloy plates on

each side of the spar form the fittings at the joints. The plates are in packs of three with one screwed ferrule to each. To ensure interchangeability, packing may be inserted between the ferrule and the plates to fix the distance between the jaws of the fittings of outer and centre-section wings. A split ferrule with tapered studs takes up any misalignment between the joints at the rear spar fittings.

Tailplane, elevator, rudder and flaps are among the last airframe units to be attached. Certain controls and the fire-extinguishing equipment are added at quite a late stage. The extinguisher includes a hand nozzle in the cockpit.

Metal fittings are made by a number of local sub-contracting firms. These units are among the last to be assembled and include the radiator duct, engine cowling, undercarriage fairings, main wing fillets and the covering strip for the joint between outer wing and centre section. The radiator duct is a neat, part-welded alloy structure attached by screws, and the main wing fillets are large curved welded units each made up of five sections of aluminium with duralumin stiffeners, anodised as a complete unit.

Simmonds nuts are used for the attachment of the undercarriage fairings, which have stiffening members attached to tubular rivets. The engine cowling is carried by the engine mounting on each side, and comprises the usual light framework braced by stiffeners. The various sections are attached by Dzus fasteners and bolts at the front.

Before the complete machine is wheeled off to the flight shed for the testing of all services, the Rotol airscrew for the Rolls-Royce Kestrel XXX engine is fitted. The blades are of improved wood and a quickly detachable V.D.M. spinner is used.

One of the most imposing departments is the dope shop, which has been built recently. This is very large and is divided into bays by movable metal partitions. At one end of the building, in a separate section, is a wood kiln.

The cockpit enclosure is built round a light-alloy tubular framework with corner and joint fittings of cast magnesium alloy. An optically true panel of ground glass is let into the transparent front sheet for gun-sighting. This front sheet is a thermo-plastic moulding. The remaining transparent sheets are plastic with acetate base.

Welded alloy construction is employed for the main fuel tanks, which have detachable sumps containing the fuel cocks. The covering panel below the wing cannot be attached after the tanks are slung in position unless the fuel cocks are in the correct position.

Small carburettor air intake scoops, one each side of the engine, lead to the filters and from these the air passes via suitable ducts to the carburettor. The filter boxes are mounted flat inside the engine cowling below the engine sump.

All wiring for the electrical equipment is carried in plastic ducts and the equipment is mounted on the structure by light alloy brackets, clips or small castings. The instruments are mounted on a light alloy panel, which is partly wired up in the shops, before attachment at an early stage, to the airframe. Electrical equipment is grouped on a panel made from plastic material.

WOOD GEODETICS

An interesting example of wood construction, employing plastic resin adhesives, is given in the CT-6A trainer aircraft developed by the Plxweve Aircraft Company in the United States.

In appearance the construction is strongly reminiscent of the Vickers geodetic structures of the Wellesley and Wellington. Plxweve geodetic construction is the result of seven years' development, and the machine has been subjected to very severe static

testing. The tail-surfaces, which in themselves weigh only 8 lbs., withstood a static load of 1,000 lbs. for 5 minutes without failure, and with the fuselage supported at the main spar and anchored at the engine mount, a 1,024 lbs. load was taken on the horizontal tail surfaces, also without failure. In a test on the wing, one main plane from the centre section to the tip was loaded with 4,400 lbs.

The method of construction consists of wrapping strips of spruce around laminated wooden formers or bulkheads, to which they are bonded by synthetic resin. All components, including the fuselage, are fabric covered.

Advantages claimed for this method of construction are that it is from 25% to 50% cheaper than a machine of similar size of metal, tooling costs are low and unskilled labour can be extensively employed for production. The machine is stated to be 50 lbs. lighter than other types of aircraft of similar size and 20 to 30 m.p.h. faster than other trainers with engines of the same horse-power.

AN ALL-METAL STRESSED-SKIN AIRCRAFT

THE SPITFIRE

One of the most famous aircraft ever built, the Vickers-Supermarine Spitfire is also one of the most graceful and attractive examples of British design. It is a low-wing cantilever monoplane and was the first British fighter embodying all-metal stressed-skin construction to go into large-scale production.

The Spitfire was designed throughout as an all-metal stressed-skin aircraft and was largely the result of the experience gained by the Supermarine Company in building

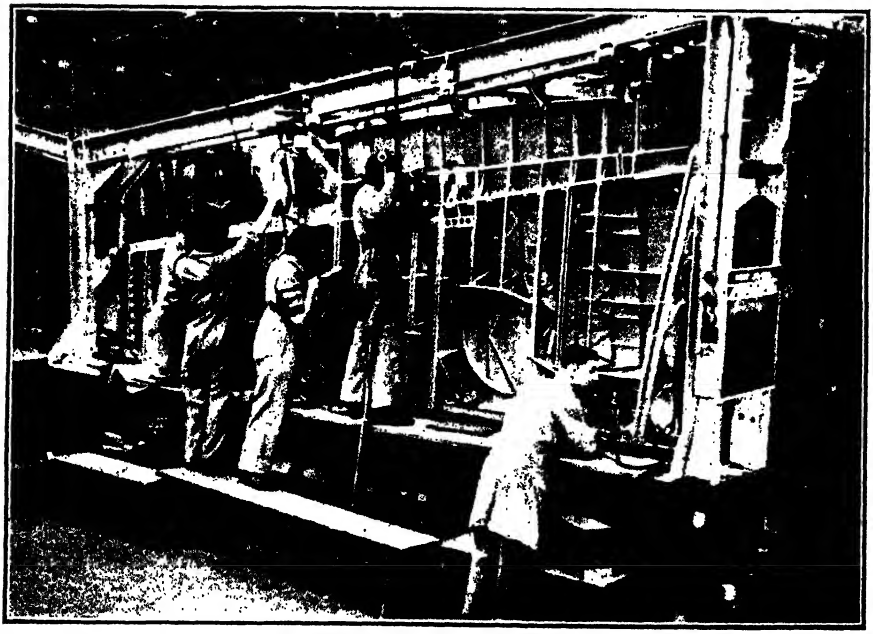


Fig. 144.—*A port wing structure in the main assembly fixture.*

the 1931 Schneider Trophy monoplanes. It was not primarily designed with a view to ease of manufacture. Some of the components, especially those comprising the leading-edge section of the main planes, are particularly difficult when considered from the viewpoint of quantity production.

The centre section, a familiar feature of most aircraft, is completely absent from the Spitfire, in which the main planes are attached directly to one of the main fuselage frames. This member is of massive construction and embodies heavy duralumin stub spars which extend across the width of the fuselage and project on each side beyond the skin plating to provide picking up points for the attachment of the main planes. This type of construction immediately raises manufacturing problems, as the wing dihedral, which in the Spitfire amounts to the considerable angle of 6°, must be obtained by cranking the spars.

Wing Construction

In fact, the whole structure of the wing, although not unique, is unusual and of special interest. Theoretically of two-spar type, it consists principally of a D-shaped

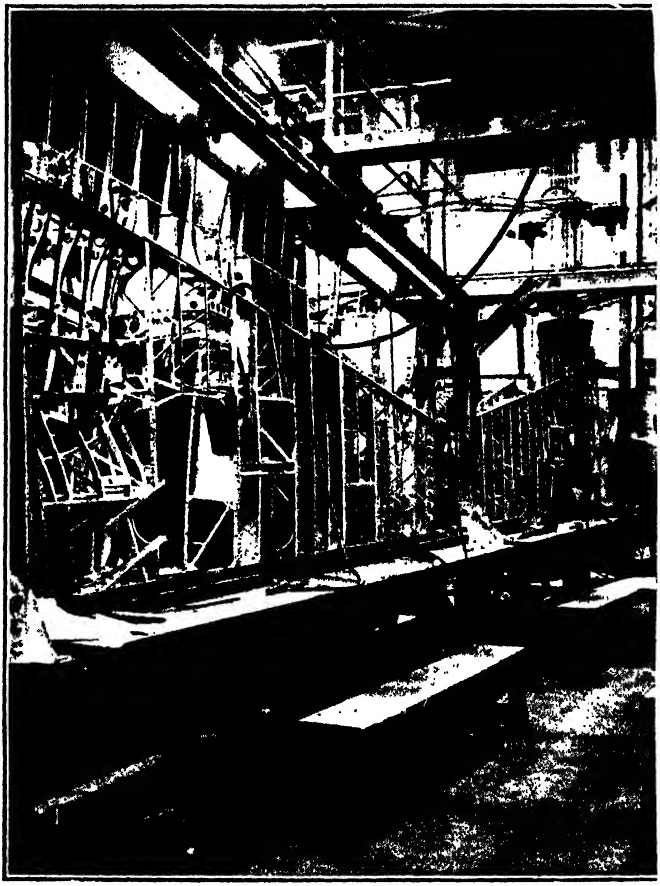


Fig. 145.—First stages of wing assembly.

section based on the front spar which forms, with the leading-edge skin, a box of great torsional strength. The rear spar is a relatively light subsidiary member of channel section connecting the trailing portions of the ribs. Actually, apart from giving torsional strength to the structure, the box section of the wing takes a large proportion of the landing loads through the undercarriage, as well as the recoil of the cannon armament. Usually the undercarriage legs are mounted on the centre plane section

of the aircraft. In the Spitfire, however, each leg is mounted on the front spar near the root end. Also, the recoil shock of the 20 mm. cannon is taken by a special mounting on the nose of the leading-edge.

In view of the varied stresses to which it is subjected the construction of the main spar is of particular interest. It is based upon two booms of square section built up from a number of extruded tubes fitted inside each other. At the root, where the boom is practically solid, there are five tubes. The centre of the innermost is filled with a 19 inch length of square bar through which a ½ inch diameter hole is drilled. As the loads on the spar decrease progressively towards the wing tip the inner tubes are terminated, beginning with the innermost, until finally only the two outer tubes remain. These are then cut away on the upper side to form a doubled-up channel section.

After a length of some two feet this is reduced to a single channel and this section is in turn cut away at one side to form a simple angle section. Corner relief between the tubes is given by maintaining a constant radius on each one at these points.

Fig. 146.—A trunnion-mounted jig for drilling the main spar components.

Boom Sub-assemblies

As has been mentioned, these booms are cranked to give the dihedral of the wing, and their production, necessarily to very close limits, is a tribute to the manufacturers, the Reynolds Tube Co., Ltd., who supply the complete boom unit, cranked and ready for assembly. To the rear face of the spar booms is riveted a single web plate flanged at top and bottom to form a channel section. Angles for the attachment of the leading-edge skin are riveted along the front faces of the booms.

From the production viewpoint the leading-edge skin, made in two sections only

for each main plane, is one of the outstanding features of the machine. At the nose of the leading-edge the two skin sections are butted together and riveted to a nosing strip on the inside. In the spanwise direction the skin is stiffened by intercostal members of Z-section, while twenty-one nose ribs of lattice- and open-girder type give chordwise support. The remainder of the wing is of straightforward construction. Viewed in plan, the bi-elliptical wing form distinguishes the Spitfire from all other aircraft. Detachable wing-tips are fitted and it is interesting to note that the two spars of the main section of the wing are carried right through the tip, which is attached by fittings on the end of each spar.

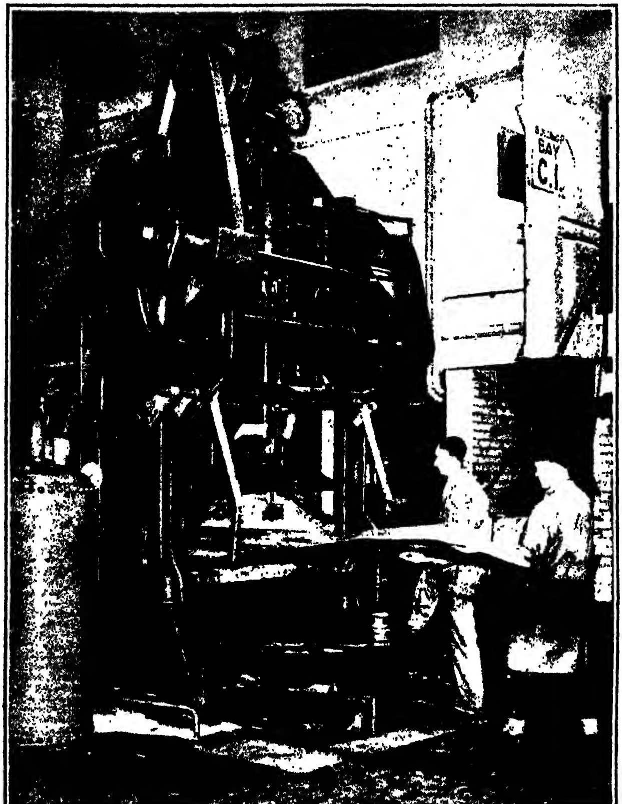


Fig. 147.—Rough-forming a leading-edge skin blank prior to stretching.

Production Processes

In the production of the Spitfire, as of other aircraft at the present time, a large and increasing number of women are being employed. By careful planning and by breaking down the different assemblies into simple operations of a repetition character, difficulties associated with this type of labour have been overcome and excellent results are being obtained.

With regard to production methods generally, manufacture is based on the system now generally adopted and highly developed in this country, of dividing and subdividing the aircraft and its components into progressively smaller assemblies. For many of the smaller units assembly fixtures may be dispensed with completely, as the different parts are produced ready drilled and assembly can be carried out on the

bench by bolting up and riveting. As a result, the larger components, such as the main planes and fuselage, are actually in an advanced stage of completion before they begin to take shape as a single unit, and the time and number of operations required in the final assembly fixture are reduced to a minimum. Such a system eliminates bottlenecks and congestion in the shops and makes possible the dispersal method of manufacture now being so successfully employed.

Sheet-metal parts for the Spitfire are produced by a number of methods, and it is interesting to observe the development of processes. For some parts which have remained unchanged in form from the Mark I Spitfire, large steel blanking and forming dies are employed. Fuselage frames are produced in this way, though routing is increasingly used and rubber-die processing is also being developed. Both of these methods make possible large economies in tooling equipment. Jabroc improved-wood press tools are also used to a considerable extent in forming components like the blister for the cannon magazine in the main plane. Formed sheet-metal units which are too large, or are of a curvature difficult to finish in the press, are shaped by wheeling, although in some cases they may be preformed in the press.

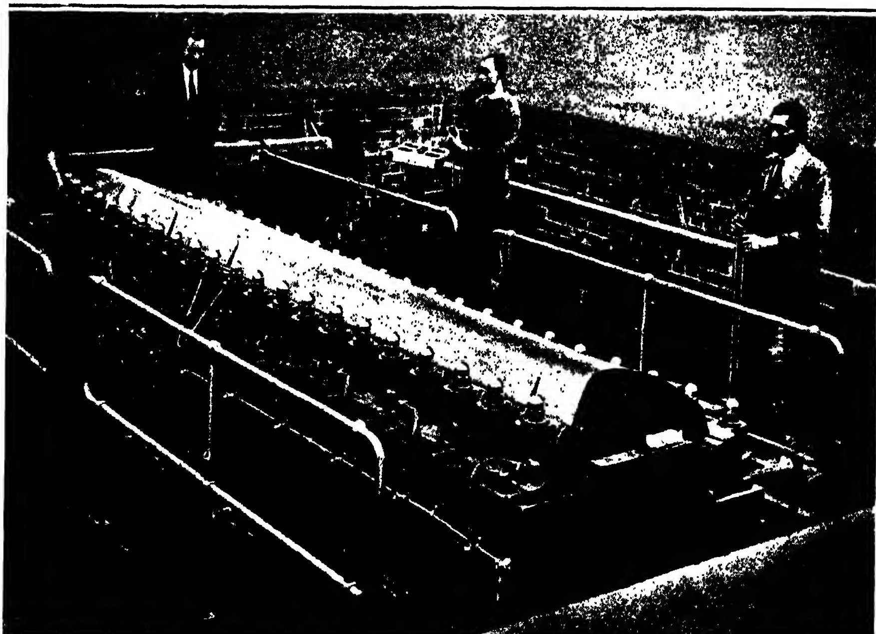


Fig. 148.—A twin 300-ton Erco Stretching Press set up for forming leading-edge skin sections.

Leading-edge Skin Sectiors

One of the most interesting sheet-metal sections of the aircraft, the leading-edge skin, is formed on the stretching press, and provides a very convincing demonstration of the possibilities of this, as yet, little used method of forming. This component, which is about 14 feet in length, is formed from a single blank of fourteen S.W.G. duralumin sheet. Apart from the size and the heavy material, the forming operation is made more difficult by the shallow curvature which gives comparatively little depth for holding the shape.

Initially the blank from which each section is formed measures 176 inches by 44 inches and is first marked out to a template for rough trimming. Keyhole-shaped notches to relieve the edges and to prevent wrinkling or tearing during the subsequent forming operation are also marked out at this stage. The edges of the blank are rough-

trimmed to the required shape on a bandsaw, after which the notches are blanked out in a hand flypress on a local blanking tool.

All burrs are then removed from the notches and the edges of the blank. This is extremely important for success in stretching, as it helps to prevent tearing of the metal, which may start from a slight roughness or local concentration of stresses in a ragged edge. At this stage the blank goes to the salt bath for normalising and is then passed through rolls to flatten it. In order to bring it to a shape in which it can be more readily inserted into the grippers of the stretching press the blank is next rough-formed or bumped on a 660-ton Craig and Donald press. The operation is shown in progress in Fig. 148. From this machine the blank goes direct to the stretching press, a twin unit consisting of two 300-ton Erco machines in tandem. There is an appreciable curve in the forward edge of the skin section to suit the elliptical form of the wing and this constitutes the reason for the keyhole-shaped notches which have already been mentioned.

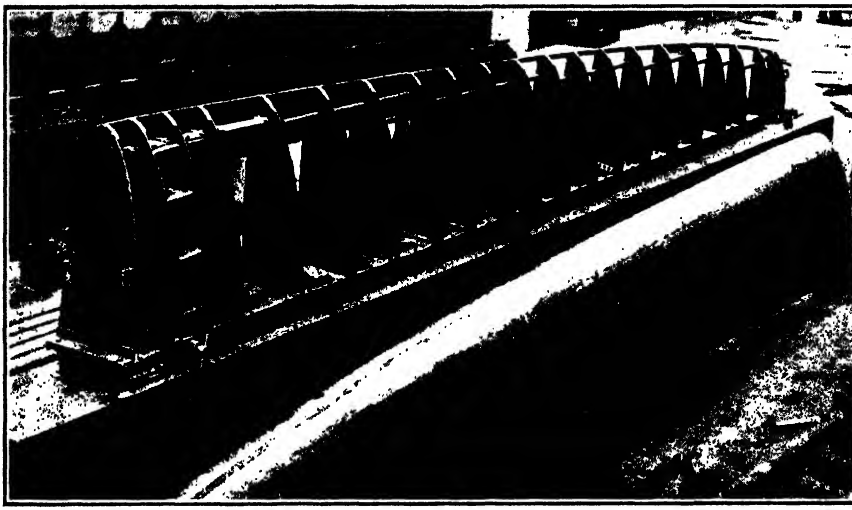


Fig. 149.—*The contour checking fixture for leading-edge skin sections.*

It will be realised that the stretching of this component on a curve from a plain rectangular blank would at least cause wrinkles and would possibly result in splitting at the edges. This danger is avoided by notches which permit the material to adjust itself to the curve. The circular hole which completes the keyhole form of the notch prevents the concentration of stress which would develop in the point of a plain V-notch and probably cause the blank to tear.

The pneumatic grippers on the near side of the machine are set round on the curve so that as far as possible constant tension is maintained and contact between the shees and the forming die is obtained simultaneously at as many points as possible. This is a considerable factor in achieving success by the stretching process. The forming die used for these skin sections is of wood reinforced at front and back edges by steel. It is along these edges, where the grippers draw the material hard down over the die, that the maximum stress occurs.

Drilling

From the stretching press the formed sheet is returned to the bandsaw, where the surplus material required for holding it in the grippers is removed Next, the secti ons are taken to the main drilling jig, which is especially interesting on account of its large size, the design of the drill plate, and the number of operations performed in it. It consists of an inclined platform upon which are arranged locations for the intercostal Z-section stiffeners of the skin.

Formed, but undrilled, intercostal members are first located on the platform, the leading-edge skin is then placed over them and the drill plate is lowered. This part of the jig is a large open cast-iron casting, the weight of which is reduced to a minimum by retaining the solid metal only in the form of a narrow strip to carry each line of drill bushes. At five points in its length the drill plate is supported on hinged arms which are counterbalanced to give greater ease in raising and lowering. Four cam-operated clamps secure the plate in the drilling position. There are some 1,200 holes in each skin section and a gang of four girls is employed to drill them, portable pneumatic tools being used for the purpose. The intercostal stiffeners are drilled at the same time.

Fig. 150.—*Assembling intercostal Z-section stiffeners to the leading-edge skin.*

Edge Trimming

Another operation performed in this jig is that of finish-trimming the longitudinal edges of the skin section to size. Two endless sprocket-chain drives are mounted in the platform and each draws a shearing knife round one edge of the skin. A strip of about ½ inch in width is removed and peels off in the manner of a wood shaving. Hand feed is used to draw the knives round, and is applied through capstan heads, one of which is mounted at each end of the jig platform. One drive operates in the horizontal and one in the vertical plane. This is necessitated by the curvature of the skin and makes practically a right-angle bend between the joint at the nose and the point of attachment to the main spar.

When drilling has been completed the skin is taken to a trimming jig, where it is mounted vertically and held by straps secured at the top by cam levers. Here the ends of the skin are marked off to templates on the jig and the excess metal is subsequently removed by hand trimming. The skin sections are also checked for form one another jig consisting of a series of templates shaped to the external profile of the twenty-one nose ribs of the leading-edge. After this the skin is laid horizontally on a stand where the drilled holes are countersunk by hand. Small local jigs located from a central drilled hole are used to drill the rings of holes for the various hand-hole covers.

Gun Ports

Ports for the guns which project through the leading-edge nose are next cut out. For this operation the skin is held underside uppermost in a cradle jig and clamped between two blocks formed to the profile of the nose. The upper block is hinged to the lower and is secured by lever-operated clamps.

Fig. 151.—A trimming jig for the overall length of leading-edge skin sections.

A hollow mill guided on its external diameter and having very narrow teeth of saw form is fed by hand into the nose of the skin and removes a partial disc in the manner of a trepanning cutter. Hand-hole apertures are next blanked out on a hand flypress, local blanking tools being used of a type similar to those employed for the keyhole notches, and located in the same manner as the drill jigs from a central hole. Completed skin sections are anodised on both surfaces.

Leading-edge Assembly

From the sheet-metal shop the skin sections go to the wing assembly, where they are built into the leading-edge. The first stage of the leading-edge construction is the assembly of the main front spar. The spar web is in three parts, each of which is a tapering flanged pressing, hand finished, of channel section. These pressings are predrilled to jig and are assembled with gusset plates and riveted as a straightforward assembly job on the bench. When this operation has been completed, the components of the spar are brought together in the main drilling jig.

The skin attachment angles are first located in the jig over the bottom drill plate and between locating pads in the walls of the jig. Next the booms, as complete units,

are dropped into position between two sets of pads, one set being attached to the jig walls and the other to the bottom drill plate. The web plate is placed over the booms and located from the flanges at each side. Finally, the top drill plate, which is made in six sections, is clamped down on top by bolts screwed into blocks mounted on the bottom drill plate.

Drilling of the web booms, skin-attachment angles, and the holes for attaching the nose rib fittings to the web plate, is carried out in this jig. Two detachable pins at each end lock the jig platform, which is mounted on trunnions and can be indexed through 180° for drilling from both sides. Traversing drilling heads are used, mounted on a bridge platform and sliding on inverted V guides at the sides of the jig bed. Drilling is commenced at each end of the jig and progresses towards the centre, two women being employed on this operation. When it is completed the loose assembly is removed from the jig for burring.

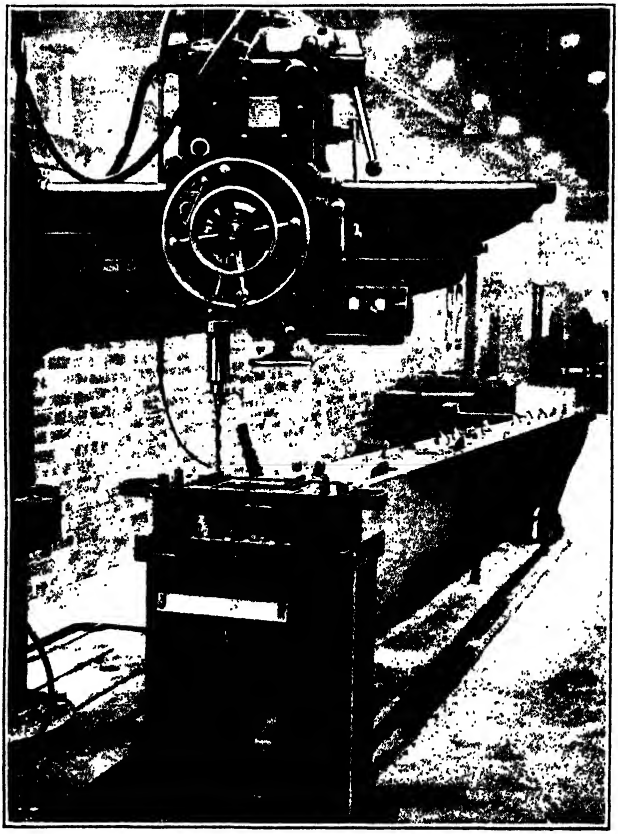


Fig. 152.—A complete port wing leading-edge assembly set up for the drilling and reaming of the spar-boom root-ends.

Assembly of the parts is the next stage. This is not done in a jig, the booms being clamped to a special type of bench consisting of a number of horizontal bars which permit free access to be obtained to the underside of the assembly. On this bench the spars are positioned at their proper centres by a location block bolted over the root ends. As all holes have been drilled, assembly of the web and skin angles to the boom is a simple matter of bolting up.

Pintle Assembly

This is followed by the assembly of the nose rib seatings on the web and the nose ribs themselves, which are of lattice-girder type and are received complete and ready for attachment from the sub-contractor. At the root end of the spar is mounted a large two-diameter pin known as the pintle. This component is the pivot for the retractable undercarriage leg and is bolted to the rear of the spar web, from which it projects at an oblique angle. It is supported by two duralumin forgings or rib posts on the front of the spar web, to which nose ribs 2 and 3 are also bolted. The securing bolts are passed completely through rib, flange, rib posts and pintle flange.

Work proceeds simultaneously on the assembly of the intercostal stiffeners to the underside of the leading-edge skin. For this operation the skin sections are held in a vertical stand, and clamped in position by heavy latches. Assembly of the stiffeners, which were drilled with the skin section, is a simple matter of tacking them in position and riveting up. Next the leading-edge assembly is located in a vertical jig with the nose ribs upward for the assembly of the leading-edge skin, the top section of which is first placed in position. For drilling the rib flanges the skin itself is used as a jig.

Joining Leading-edge Sections

At the nose of the leading-edge the two skin sections are brought together to form a butt joint, which is secured by a strip inside the nose, formed to the contour of the rib tips, and riveted to each section, as shown in Fig. 149. At this stage of assembly the nosing strip is laid in position over the ribs and drilled from the skin sections, which are then riveted to it. Flush riveting is used over the whole of the leading-edge

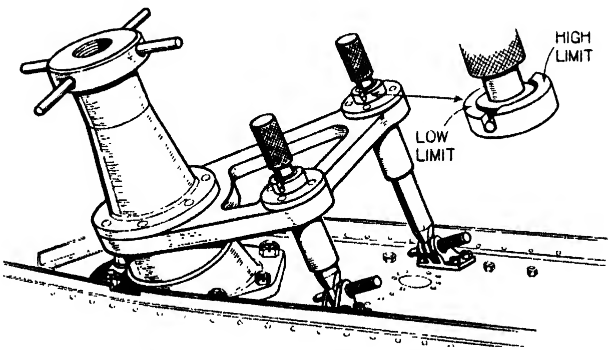


Fig. 153.—Details of the special gauging fixture used to check the alignment of the undercarriage locking-pin fittings on the spar from the pintle.

but is not of the type usually implied by this term. Countersunk head rivets are not used. Instead, an external pan head is formed by holding up in the usual way with an internal dolly and hammering the shank into the countersunk hole in the skin. The portion projecting above the surface is then removed by a pneumatic chisel. In this way a machined flush surface is obtained. Riveting of the lower surface skin to the ribs is finished before the second section is applied. Access to the interior for riveting the top skin is obtained through a series of hand holes in the lower section.

Main Attachment Holes

When the skin-plating operations have been completed the whole unit is taken to the radial drill shown in Fig. 152 for the drilling of the fuselage attachment holes in the spar booms. For this operation the leading-edge is located at the outboard end by the wing-tip attachment fitting on the spar. At the root the assembly is supported beneath the ends of the booms and location is effected by a setting bar, which fits over the No. 1 rib attachment lugs on the rear face of the spar. In its turn this bar is positioned laterally by locating pins inserted through the standing portion of the jig. The boom ends are held down by a heavy clamp.

Three operations are necessary, drilling, rough-reaming and finish-reaming, and for each one a separate bush plate is used. These plates are located at each side by

a detachable plug engaging in the base of the jig. The jig structure itself consists of cast-iron supports for root and tip locations bolted to each end of an inverted channel, grouted into the floor. Both port and starboard assemblies can be accommodated in the one jig. In each case the spar root has the same location, but the outboard end is located by the wing-tip spar fitting on opposite sides of a cast-iron jig standard. The same bush plates are used for each unit, but they are inverted as required to suit the " hand " of the assembly.

Checking Undercarriage Fittings

After the completion of drilling, the angle of the pintle and its position relative to the undercarriage locking-pin fittings are checked. A gauging sleeve is placed over the pintle locating on two machined diameters and against the main abutment flange. An alignment plate is screwed to one side of the sleeve and when this has been squared up to No. 1 rib fittings the angular face at the top should be horizontal. This face is checked in two positions mutually at 90° by a Watts clinometer. If the assembly is correct the instrument will give a zero reading in each case.

The undercarriage locking-pin fittings on the spar are also checked for alignment and position in relation to the pintle. A gauging fixture of the flush-pin type is used for this purpose.

In the flush-pin gauge, which is a special application of the plug and ring type, the permissible tolerance is indicated by high and low surfaces on the ring portion, and the degree of accuracy of the part being gauged is shown by the position of a shoulder on the plug in relation to these two surfaces. The gauge shown in Fig. 153 is located on the pintle in a similar manner to the one just described by a sleeve which can be clamped in place by a ring nut. This sleeve carries a frame, roughly triangular in shape, with a gauging hole at each of its outer corners, corresponding with the two locking-pin fittings of the spar. The bearing length of each hole is increased by a collar attached to the upper face of the frame. Each collar forms a ring of the gauge and the high and low limit surfaces are arranged as shown on each side of the central slot.

Gauging plugs inserted through the collars pick up the spar fittings by locating pins passed through the attachment lugs and the " flatted " ends of the plugs. A shoulder on each plug shows whether the spar fittings are correctly mounted. If the assembly is within the permissible limit the shoulder will be between the high and low surfaces of the ring. Extreme limits of the tolerance are shown when the shoulder is flush with one of the two surfaces. A pin on each gauging plug shows by engagement with the central slot in the ring whether the angular position of the spar fittings is correct in relation to the pintle.

Cannon Bay Structure

This inspection completes the operaticons on the leading-edge as a separate assembly. With the exception of the interspar setion known as the cannon bay, the assembly of the wing structure is completed in the main fixture. The cannon bay section comprises the interspar structure in the four rib bays from No. 8 to No. 12. This fixture is of very simple, open construction, consisting only of two channel-section columns connected by two members of steel plate representing the wing spars and carrying dummy pick-up fittings which serve as locations for the ribs. Ready access is obtained to all parts of the structure, which is very cheap to build.

All the smaller units assembled in this fixture are, in themselves, complete sub-assemblies. Rib No. 8, complete with aileron-control pulleys and ammunition chute, is positioned by its spar attachment fittings at each end, and rib 12 is similarly located. A special structure is required in the cannon bay as a mounting for the cannon magazine, which is later mounted in the wing between ribs 9 and 11. This structure includes an auxiliary spar and a rear skin former with armour plating. Short, lattice-type ribs connect these members with the front and rear spars. In the under surface is mounted the framing of the retractable landing-lamp aperture. Steel templates are used to position the magazine structure and the framing for both magazine door and landing lamp, and in the case of the magazine door to locate the position of the fasteners on the structure. All the members of the structure are located on the jig, drilled where necessary from the mating member, and riveted up.

Main Assembly Fixture

The main wing fixture is an open frame of rolled-steel sections, consisting of double end and centre columns of channel-section steel placed back to back and braced by horizontal cross-members. At the top the columns are connected also by two

channel-section members. As with all Spitfire main component assembly features, Consolidated spring-ratchet counterpoises are mounted above the fixture, so that portable pneumatic tools can be suspended at a convenient height and be always ready to hand.

Two wings can be accommodated in each fixture with the roots at the outer ends. The wings are assembled with the leading-edge downward, locations for the spar roots and wing tip fittings being arranged on the end and centre columns. The top member bridging the columns is inclined at an angle to suit the taper of the wing and carries locations for the aileron hinges as well as subsidiary locations for the remaining rib tips. In this fixture the wing is arranged so that the rear face of the front spar is at convenient working height above the stepped platforms which extend the whole length of the jig.

Interspar and Trailing Structure

On this face, the interspar ribs are next assembled, No. 1, at the root end of the wing, Nos. 14 and 19, aileron hinge ribs, and No. 21, at the tip end, being first placed in position. In this way the interchangeability of the key points such as the aileron hinges and the wing tip fittings is assured.

Between the spanwise sections formed in this way, the rear spar is assembled in parts, which are attached to pre-drilled angles on the ribs. The remaining ribs are assembled between the spars to attachment brackets already in position. The cannon bay structure is assembled as a unit between the spars at this stage and the aileron differential gear is fitted to the rear spar. Trailing flap ribs are then riveted to the rear spar, between the aileron gap and the wing root.

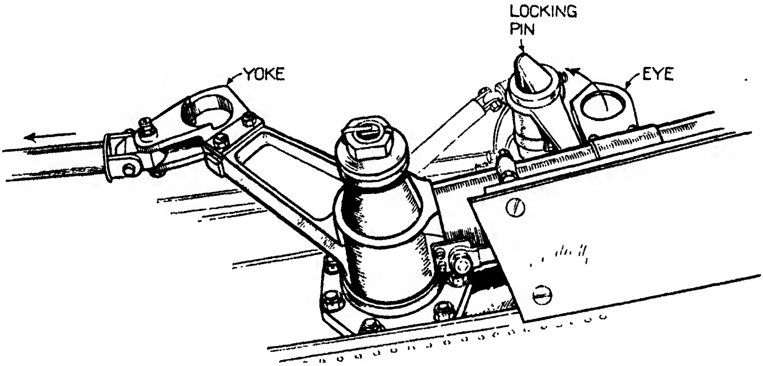


Fig. 154.—Details of the undercarriage locking mechanism.

At the tips, these ribs are connected by a duralumin trailing-edge strip which is recessed on the underside to permit the trailing-edge tips of the flaps to fit flush into the aerofoil section of the wing. In the jig the strip is located by this recess on a contour bar hinged from the top member of the jig. The rib tips are riveted to the trailing-edge strip by small triangular gusset plates.

On the port wing the skin of the upper surface is supported over the radiator bay by a system of light flanged formers and spanwise members having the character of light auxiliary spars. These members are riveted in place between the front and rear spars. A similar construction is used over the wheel housing, which is finally enclosed by a circular sheet-metal partition. To position the leg and wheel housing structure, a jig or "mock-up" leg is fitted to the pintle fitting on the main front spar.

The structure is then ready for the application of the skin plating. The upper surface skin is applied first, the panels being drilled from the rib flanges, tacked in place by locating pins and riveted. Assembly of the upper skin is a relatively easy process, as there are few apertures and the surface can be covered by panels of a comparatively simple form. Also, accessibility to the interior is easily obtained, and holding up for riveting can be readily effected.

On the lower surface of the wing the problem of applying the skin is complicated by the number of apertures, such as the radiator compartment, the wheel wells and

the openings for the retractable landing lamps. These necessitate the subdivision of the surface into a large number of sections which are drilled on the jig from the ribs as the shallow curvature, combined with the somewhat intricate shapes, make it impracticable to pre-form and pre-drill them before assembly. Holding up, for riveting the underside skin, is effected through various hand holes and inspection covers and through the gun-access doors in the upper surface.

Installation of Services

Installation of the internal gear follows the application of the upper skin and includes the running of the electrical wiring conduits, aileron control cables, and the fitting of compressed air piping for guns, flaps and landing lamp operation. Assembly of the shroud along the aileron gap is one of the last operations to be performed before the wing is removed from the assembly fixture.

A considerable amount of work still remains to be done at this point, and while it is in progress the wing is supported, leading-edge downwards, in a felt-lined cradle. The oleo-pneumatic undercarriage leg, which is of Vickers design, is fitted to the pintle and the wheel is assembled on it.

Undercarriage Actuation

Each undercarriage leg is actuated through a bell-crank extension at the top of the oleo-leg. At its outer end this extension carries a yoke which has a forked extremity for the attachment of the control-rod from the hydraulic operating jack in the fuselage. This yoke is also bored to receive the pin and locks the leg in its down position. The actuating mechanism is shown, with the pin about to engage in up and down positions, in Figs. 154 and 155. It will be noted that a bored fitting is attached to the oleo to engage the locking pin when the leg is retracted. A bracket mounting on the rear face of the main spar is provided for the spring-loaded locking pin, which is of tungum, 1½ inches in diameter. At the end it is cut away on an angle to act as a lead.

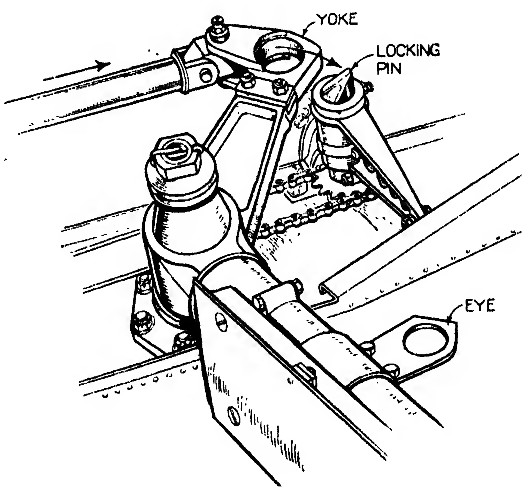


Fig. 155.—The undercarriage leg nearing the down position.

When it is necessary to disengage the leg from its locked-up or locked-down position, this pin is first rotated by sprocket gearing through an angle of about 180°, so that it can be forced down into its socket by the trailing action of the locking fitting against the angular face as it moves over the pin. In this position, also, the angular face is presented towards the other fitting which automatically engages the pin in the same manner and locks the leg in position. This locking and releasing is actuated in conjunction with the main chassis operating unit lever, which automatically times all operations. A visual indicator for the undercarriage is incorporated in the operating

gear and is assembled at this stage. It consists of a short rod, bearing the words " wheels down," which projects through the upper surface of the wing when the oleo-legs are lowered.

In the underside of each wing is mounted a retractable landing-lamp, and this and its operating pneumatic jack are fitted and connected up. The wing tip is attached by its two spar fittings and by 2BA screws and Simmonds floating anchor nuts around the joint between the two sections of skin plating. At this stage also the flaps are fitted and connected to the operating jacks. These units are in two sections, shown clearly in Fig. 156, a straight portion extending from the aileron gap to the commencement of the dihedral and a small curved section from there to the root of the wing. This arrangement is necessitated by the difficulty of obtaining hinge alignment in a single curved unit covering the whole length. A pin projecting at an angle from the longer section and working through a ball joint operates the shorter portion simultaneously.

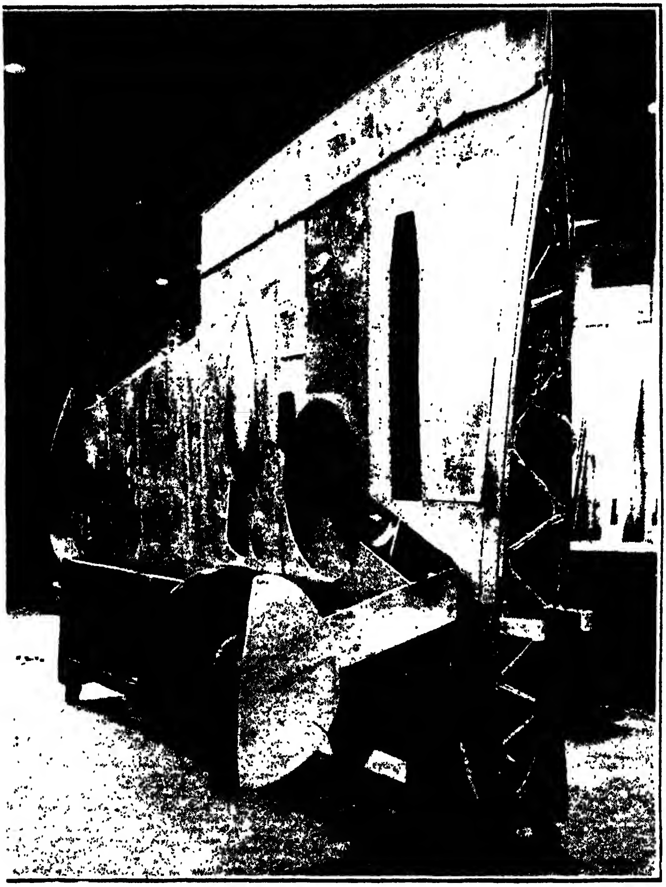


Fig. 156.—Final stages of wing assembly with the wing held in a felt-lined cradle.

Final Operations

The machine-guns are mounted on their stirrups, but the fitting of the cannon is not done until the later stages of final assembly. Gun-heater tubing, of black cellulose-acetate, is next installed and brought out to the wing-roots ready for connecting up. When the machine-guns are in position the access doors are fitted in the upper surface

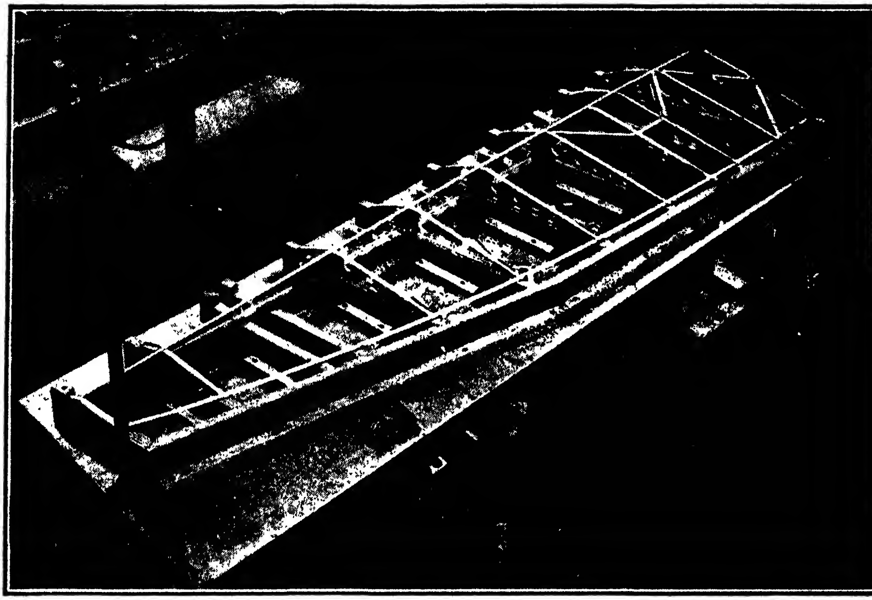


Fig. 157.—*A plywood fixture is used for the first stages of aileron assembly.*

Fig. 158.—*The second stage aileron assembly fixture, showing the nosing held down to the framework by balata strips.*

of the wing. All remaining covers are fitted, including the cannon magazine blister and the black cellulose-acetate covers, through which the hot air emerges from the gun-heating installation. Finally, the wing is cleaned internally by vacuum apparatus and after being removed from the cradle is taken to an adjacent Carrier spraying booth, where it receives the first coating of grey paint and the blazons are painted on. This booth is lighted by daylight fluorescent lamps behind glass panels in the walls. Excess pigment from the spray guns held in suspension in the air of the booth is extracted by fans.

Ailerons

Formerly a fabric-covered structure, except for the nose, the aileron is now entirely covered with a metal skin. There are two stages of assembly and two fixtures. The primary structure of ribs, spars and trailing-edge is assembled in a fixture constructed from nine-ply wood. Each member of the structure is located on a vertical plywood former shaped to the proper profile. Lateral location for the ribs is given by vertical steel plates through which locating pins are passed through tooling holes in the rib webs. The spar is of channel section with doubling plates at the hinge attachment points, and is located on tooling holes and clamped to vertical location plates at three points, while the triangular-section trailing-edge strip is located in small recessed steel

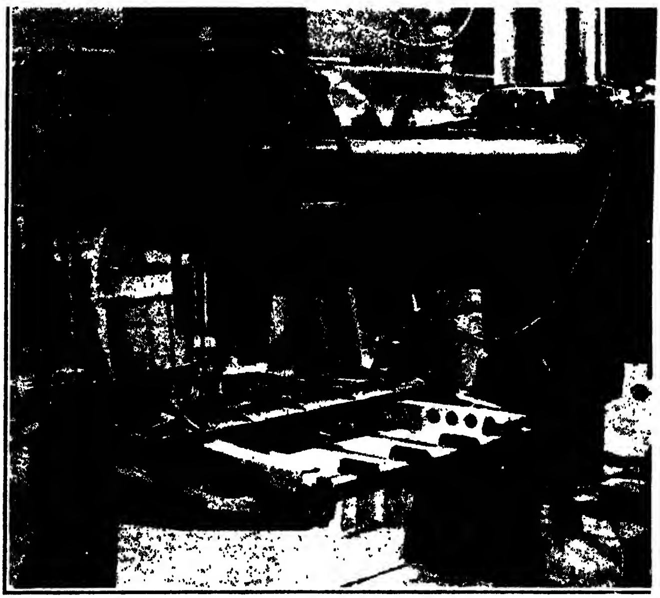


Fig. 159.—First stage drilling jig for frame 5 of the fuselage.

plates. " Full former " location plates for the end ribs also govern the overall length of the unit. In the tips of nose ribs 1, 2 and 3 is carried the aileron balance, which takes the form of a screwed rod extending over the two rib-bays. Extra weights can be added as required. The hinges are assembled as small sub-assemblies, complete with mounting brackets, at a later stage in the final assembly fixture.

This fixture consists of a platform at convenient working height upon which are mounted two cast-iron brackets, one at each end. These serve as locations for the end ribs of the aileron and also as supports for the L-section members, extending along each side of the fixture. In their turn these members support the two hinge locations and locations for the aileron spar.

Location for the structure already assembled is taken in this fixture from the same tooling holes in the spar web as were used in the first stage of assembly. At the tips the ribs are also positioned on the same tooling holes in the webs by locations mounted

at intervals along the fixture platform, and the framework is clamped in place through the lightening holes in the spar web. The hinged sub-assemblies are set on the locations, and after the structure has been drilled from the mounting brackets they are riveted in place. These locations on the fixture for the hinges are retractable and can be locked in the assembly position by detachable pins They are withdrawn after the assembly of the hinges to permit the leading-edge skin to be placed in position over the nose ribs.

Skin Plating

The nose skin is of elongated U section made under sub-contract. It is supplied formed with the hinge apertures roughly cut out. It arrives in this condition at the assembly where it is marked out on the structure and drilled, afterwards being removed for countersinking in readiness for flush riveting. On this fixture the nose skin is held down by balata strips which are tightened by turning handwheels on the platform. The spar flanges are drilled from the skin.

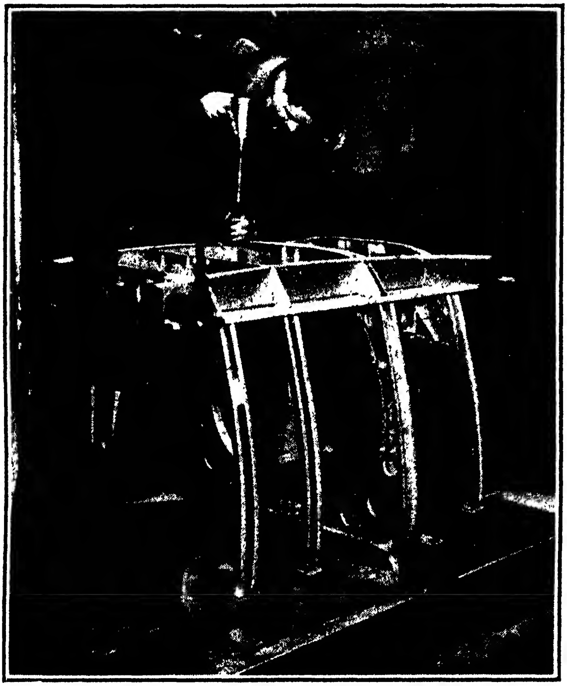


Fig. 160.—Frames for the cockpit section of the fuselage.

The main portions of the skin plating, consisting of one panel for each side of the aileron surface, joggled to fit under the nosing, are also marked off from the ribs, drilled through and taken off for countersinking. This preliminary work on the trailing portions and all riveting is done on a separate riveting stand upon which the skin panels are first cramped and then tacked in place by locating pins. Solid flush rivets are used to rivet the skin on the first side, but Wyrlie pop-rivets are used on the second side when access is not obtainable to the interior for holding up. The skin plating is joined to the trailing-edge strip at each side, the edges being brought together at the extreme tip and tapered off to a point on the inner faces.

Completed ailerons are statically balanced on knife-edges about the hinge centres, the weight in the nose being suitably adjusted, as previously mentioned. This work is performed by women.

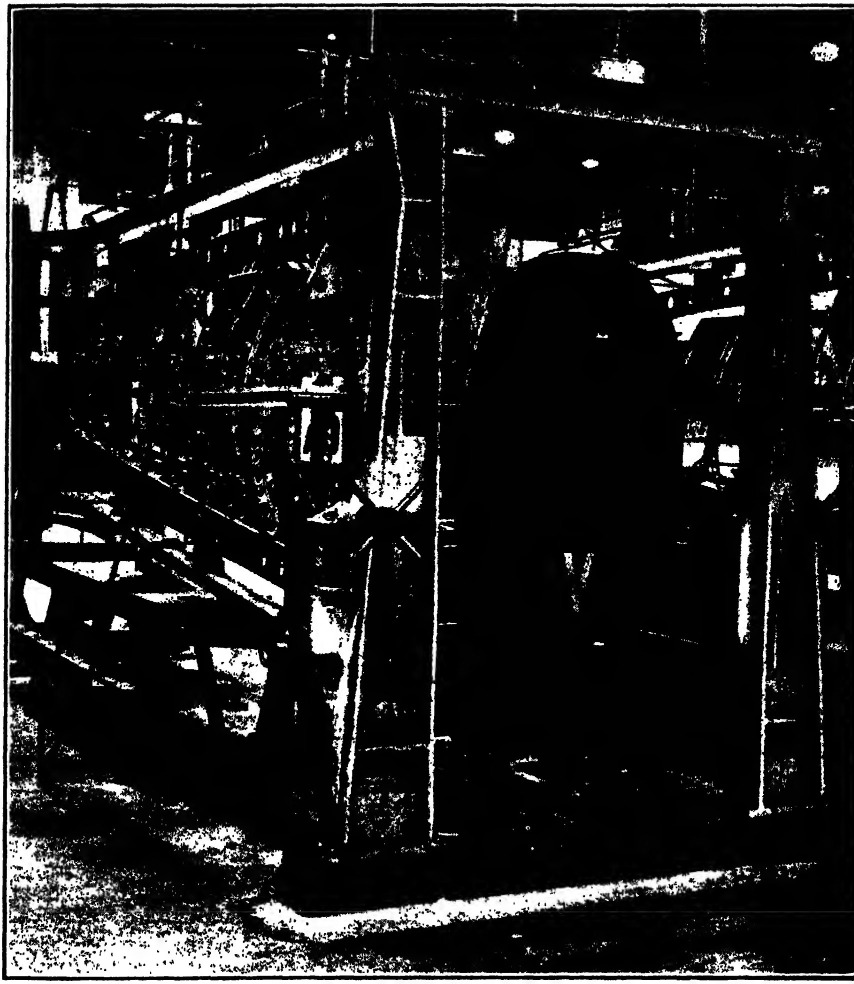


Fig. 161.—*One of the main fuselage assembly fixtures.*

Building the Fuselage

The Spitfire fuselage, taking the whole length of the aircraft, actually comprises three separate sections: the engine mounting, the fuselage proper, of monocoque construction, and the stern portion, which includes the fin as an integral part. The main monocoque portion extends from frame 5 to frame 19, where the stern portion is bolted on. Details of its construction are shown in Fig. 168. Frames are of flanged, sheet-metal construction with lightening holes, and the structure embodies two bottom longerons of V-section extending the whole length of the unit, and two side longerons of bowler-hat section terminating three frame bays aft of the cockpit. Behind the cockpit the frames are connected at the top by a V-section dorsal longeron, which is divided at its forward end, where the aerial mast and upward identification lamp assembly are accommodated. The top engine-bearer pick-ups are bolted to the front ends of the side longerons; the lower pick-ups are bolted through the stub spar of frame 5 to fittings on the bottom longerons.

Frame 5 may be regarded as the heart of the airframe, as it carries the engine-bearer pick-ups, the main plane attachments and generally takes the place of the normal centre-plane unit. It forms the main sub-assembly of the fuselage structure, and is of composite construction, comprising an upper and lower fireproof bulkhead attached to the stub spar-booms by which the wings are bolted to the fuselage.

Main Frame Assembly

To a large extent the building of frame 5 consists of assembling finished units, and much of the work is done on the bench. On the upper fireproof bulkhead procedure is straightforward, the asbestos sandwich of which it is composed being received as a unit at the assembly. Here the three vertical stiffeners seen in Fig. 164 are tacked in position with the cowling attachment flanges round the periphery and the cowling rail fittings on the front plate. The lower portion of the frame is first assembled as a separate unit, consisting of the forward spar web plate, with its three vertical stiffeners similar to those on the upper bulkhead, two curved U-section side-members, the aft spar web members, and the lower fireproof bulkhead, also consisting of an asbestos sandwich. Stiffeners between the two web plates and a cross-member of heavy tops hat section between the side longeron attachment points also form part of this first assembly, which is built up on the bench and then transferred to the large drilling jig shown in Fig. 160.

In this jig the wing root pick-up holes and the spacer attachment holes are drilled. The spacers are small duralumin forgings interposed between the two web plates to maintain the correct distance between front and rear spar booms. Drilling is performed from both sides, in the front web plate through bushed holes in the jig platform and in the rear web, from a removable drill plate which bridges the entire frame. It is supported at each end by machined pads and is located by detachable pins. Handles are fitted for ease of manipulation.

Another drilling operation performed in this jig is that of drilling the top-hat section cross-member for the side longeron attachment holes. For this purpose a separate detachable jig is used. It consists of two bushed plates connected by four bridge pieces and fitting over the outside of the channel. At each end the outer plate terminates in a collar locating over a post mounted in the jig platform. Swing washers are fitted for rapid securing and removal. Three holes are drilled in each end of the cross-member from this jig, and to do this it is necessary to swing the whole jig platform through 90° by the index plate seen at the left.

Second Stage Frame Assembly

After the partial assembly has been removed from the jig the spar booms and spacers are assembled and the upper and lower sections of the frame are riveted together through the front spar web and the upper bulkhead. The assembly is then placed, rear side upward, in a second jig for the reaming of the engine-mounting holes and the three holes which take the main connecting bolts between each end of the spar booms. In this jig the assembly is located by one wing spar attachment hole at each end of the stub booms, and drilling is again performed from both sides. In the rear stub booms the holes are drilled from separate drill plates located by removable pins at each end, as in the first stage jig. For the upper engine-bearer bracket locations separate drill plates are used bolted to the sides of the jig platform. All these drill plates are fitted with swing washers under the securing nuts for quick removal and rapid unloading of the jig.

Both main drilling jigs are served by the one Archdale radial drill, around the column of which they are disposed at a spacing of 90°. Both are of similar type, and the work platforms can be indexed through 180° for drilling from both sides. Following the removal of the frame from the second jig, the lower engine-bearer fittings, lower longeron pick-ups and the jacking pads are assembled to the bottom spar booms.

Assembly of the monocoque portion of the fuselage from frame 5 to frame 19 commences on the bench and actually proceeds out of the jig until the skeleton structure of frames and longerons is completed. In building up this structure the dorsal longeron is first clamped to the bench and the frames are assembled to it and temporarily bolted up. The larger frames of this section are made in halves, the two pressings being joined on the vertical centre line of the fuselage. The smaller frames at the rear of this section are made as single pressings. Apart from frame 5, one other section of this structure, comprising frames 6–9 with the appropriate section of the lower longerons, is built as a separate sub-assembly. This unit is built up in the usual way from finished parts in its own assembly fixture.

Main Assembly Fixture

As all these parts are accurately jig-produced, assembly may proceed on the bench until the skeleton structure is ready for the main assembly fixture. In design this fixture consists of an open framework, partly of cast-iron and partly of structural steel sections. At the front end the columns are massive castings of heavy I-section ribbed for maximum rigidity and bridged at the top by a horizontal square-section member of cast-iron. These columns carry the main jig locations for the stub spars and for the top engine-bearer attachments on frame 5. All these locations are retractable laterally to make possible the withdrawal of the complete unit from the fixture. The wing pick-up locations are withdrawn by rack-and-pinion gear operated by capstan heads on the front columns. In the case of the upper engine-bearer locations, which consist of simple forked fittings, the whole bar is a sliding fit in its bearing on the column and can be pulled straight back after detaching the locking pin, which holds it in the assembly position.

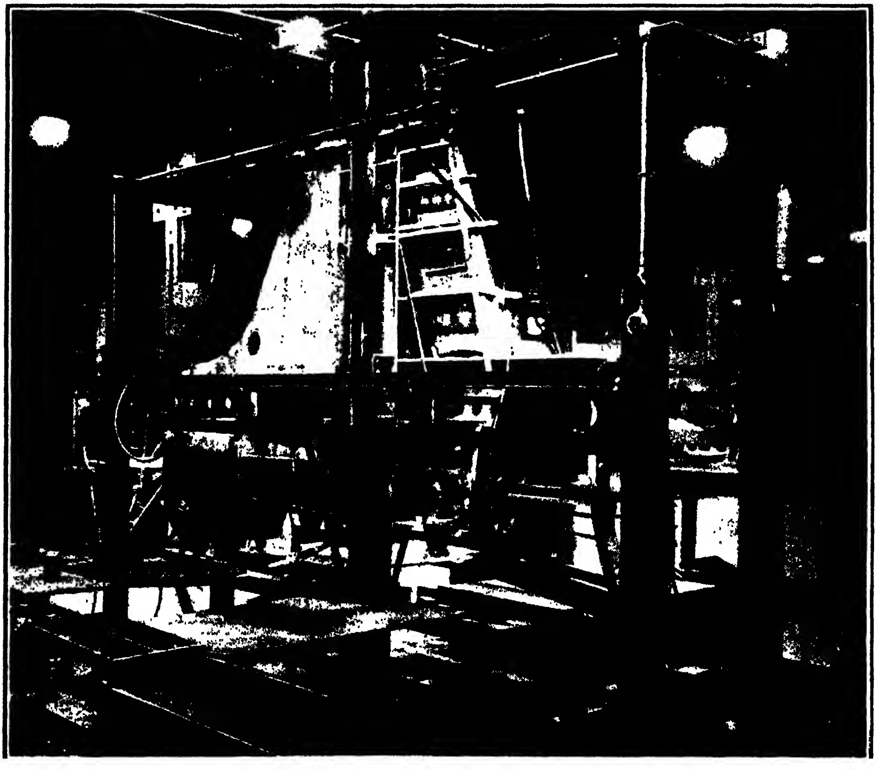


Fig. 162.—Paired-up assembly fixtures for rear fuselage units.

At the back of the jig, the cross-bracing of the columns carries a location plate for frame 19. This component is bolted back to the plate and positioned by the holes by which the rear section is attached at a later stage.

At the top and bottom of the fixture are central keel members which carry locating strips shaped to the top and bottom contour of the fuselage. Locations for the frames are mounted on these strips and take the form of small angles at intervals giving the correct frame stations. When the skeleton fuselage is inserted into the jig the frames are located at top and bottom by small wire pins inserted through the angles into tooling holes in the frame flanges.

The upper engine-bearer fittings are fitted in this fixture to the ends of the side longerons on frame 5. For this purpose the two upper locations on the front jig columns are advanced and locked in the assembly position. The engine fittings are located between the pick-up jaws with the shank lying in the longeron channel.

After the attachment holes in shank and longeron have been opened out the fittings are bolted up. The wing rear spar fitting is assembled in the same manner to a location on the fixture which ensures its position and interchangeability for wing attachment.

Remaining operations in this fixture are concerned principally with the application and riveting of the skin plating. This consists of 18, 20 and 24 S.W.G. Alclad, decreasing progressively in thickness towards the stern, and the panels are received at the jig ready formed and drilled and with intercostal and stringer sections attached. In the Spitfire fuselage the stringers are not continuous but consist of separate Z-section stiffeners or intercostals riveted between the frames. Application of the skin in the jig commences with the attachment of the top and bottom sections. The bottom sections are applied first, and, to do so, the frame location pins are first withdrawn from their pick-up angles. The skin panels are then slid into place, there being

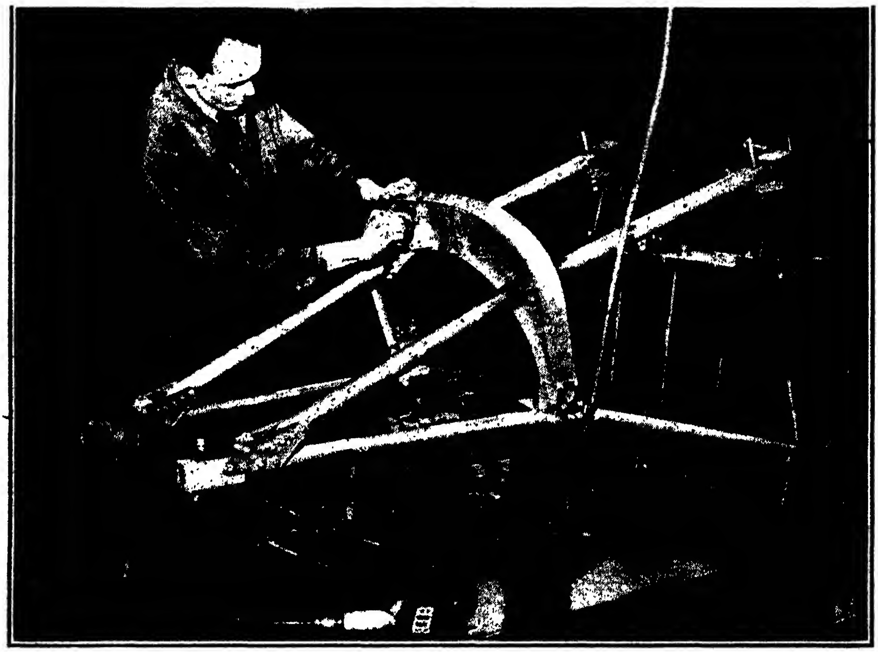


Fig. 163.—The tubular engine mounting in inverted position.

sufficient clearance between frames and pick-ups to admit the thickness of the sheet, while the angles are shaped to the curve of the fuselage and afford a certain degree of support.

Frame flanges are drilled from the skin panels and the attachment brackets on the frames from the intercostals or stringer sections. The bottom skin sections are pre-formed initially by stretching and checked finally to a wooden jig former or mock-up of the appropriate portion.

They are received at the fixture drilled and with intercostals assembled and riveted. The bottom forward skin-section is applied in this manner as a complete sub-assembly with downward identification lamp framing and access aperture complete.

Flush riveting is used for the fuselage skin as far back as the rear of the cockpit. Aft of this point snap-head rivets are used, as the ill-effect of drag caused by projecting

heads is not so pronounced. Similarly, the joints between the skin panels are joggled from the front to the same point, presenting a flush surface, but aft of the cockpit they are lapped towards the tail.

After its removal from the main assembly fixture the fuselage is taken to the jig for the reaming of the main wing attachment holes in the stub spars on frame 5, and for the drilling of the wing-root fillet holes in the skin plating. In this jig the fuselage is located on the stub spar and rear spar fittings. Two compressed-air motors are used in reaming the main spar attachment holes. The reamer socket is connected to the motor spindle by a flexible drive through two universal joints. This arrangement is adopted to accommodate any slight misalignment between the motor spindle and the reamer guide bush.

The motor mounting is carried on small wheels and can be moved along the jig frame to bring it in line with each guide bush. A compressed-air piston beneath the mounting raises it into position when required for the upper line of holes. In feeding the reamer into the work the motor is moved bodily forward on its mounting through a lead-screw operated by a handwheel.

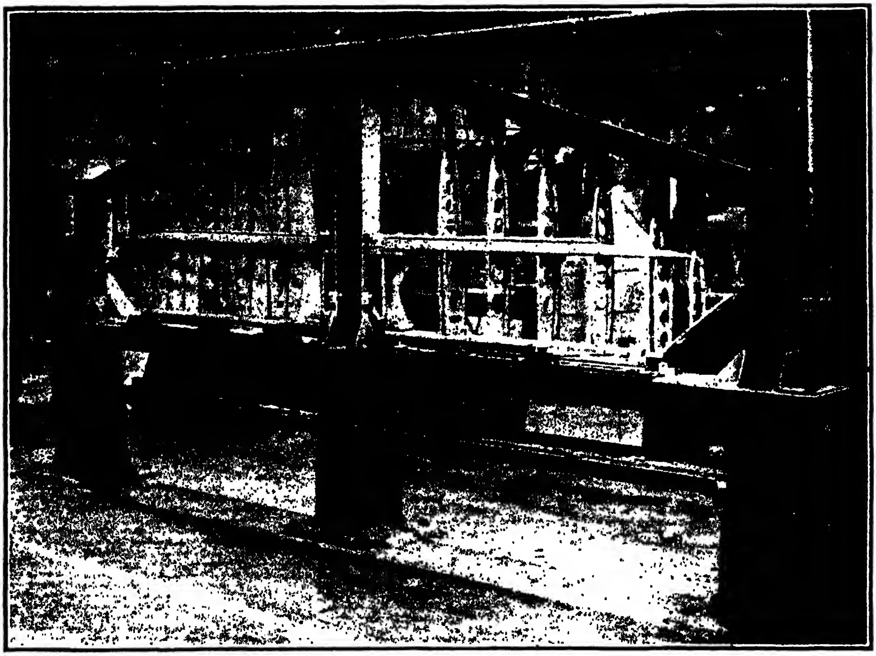


Fig. 164.—Twin fixtures for assembly of the tailplane surface.

Detachable pins are used in two of the holes for the location of the fuselage. To open out these holes the pins are withdrawn one by one and re-inserted in two other holes, pins of two diameters being used to suit the holes before and after reaming. Drilling of the attachment holes for the wing-root fillets is effected by a template type of jig built up from steel strip and section, integral with the main jig and extending along each side of the fuselage.

Hardened drill bushes for the fillet holes are carried in the curved periphery of the jig and a portable tool is used for drilling the skin plating. Inside the fuselage, intercostal stiffeners are attached to the skin along the line of holes to strengthen it at the points of attachment. These two fillet drilling jigs form a cradle into which the fuselage is lowered.

This jig with its positive location of the fuselage ensures absolute interchangeability of the main wing attachments. Although the drilling of the fillet attachment holes

does not need to be so extremely accurate as to position, it would be clearly impracticable to drill the skin panels before assembly in the expectation that they would align for attachment purposes with those in the fillet.

After being removed from this jig the fuselage is vacuum cleaned before being taken to the Carrier spraying booth where camouflage and blazons are painted on. It is then ready for final assembly.

Rear Fuselage

A somewhat unusual feature of the Spitfire is that the fin surface of the tail unit is an integral part of the rear fuselage. This section completes the fuselage aft of frame 19 and is built in an assembly fixture, the structure of which is kept as open as possible to give maximum accessibility consistent with rigidity.

Another regular feature, the fitting of overhead counterpoises for the portable pneumatic tools, may also be noted. The fixtures are built in pairs, two units being assembled back to back, and the structure consists of two columns of I-section at each end set into the floor and braced by L-section cross-members at the top and near the bottom.

Along the sides of the fixtures are L-section members carrying cast-iron crosspieces which serve as dummy tailplane spars. Frame 19 in the rear fuselage structure is little more than an L-section former which bolts on to the back of frame 19 proper at the rear of the main fuselage section. In the rear section assembly fixture it is located by its attachment points on an inclined plate, to which it is held by screws and wing nuts. Frame 20, the rearmost of the actual fuselage frames, is located on the front of the tailplane dummy front spar, the attachment points again being used for the purpose.

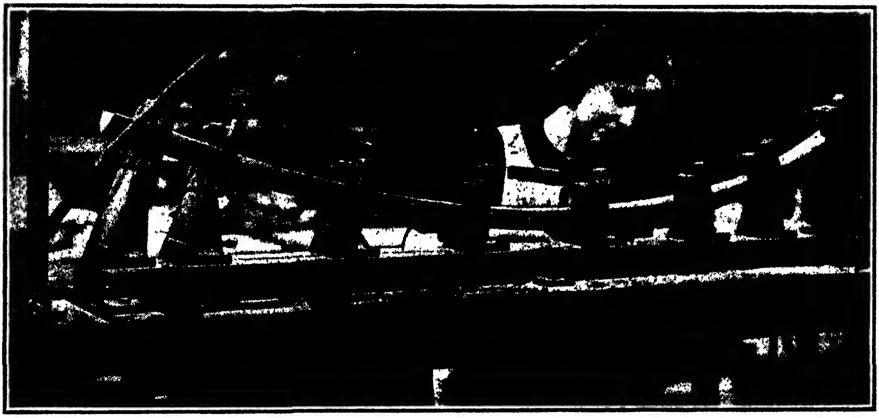


Fig. 165.—Drilling the nose skin for the tailplane leading-edge.

On the rear face of the same dummy spar, frame 21 is located. This is of banjo form—and is known by that name in the shops—shaped at the bottom to serve as a frame for the rear portion of the fuselage, while the tapering extension at the top forms a front spar for the fin structure. This member is routed from a flat blank and set to the required angle after being flanged in the press.

Frame 22 is of similar shape and is located on the front face of the dummy rear spar in the same manner by detachable pins. The fin post is carried on the rudder hinge-fittings, dummy mating fittings being mounted on the centre column of the fixture. In this way all the pick-up points between the rear fuselage, the tailplane and the rudder are accurately located and interchangeability of manufacture is assured.

Assembly procedure is straightforward. Stringers are assembled in the fuselage portion between the frame and tacked and riveted to the flanges. Nose ribs or formers are riveted to fittings on the fin front spar (frame 21) and interspar ribs between its rear face, frame 22 and the fin post. Tension members are fitted between the bottom rudder hinge position on the fin post and frame 21. In applying the skin, which is of 22 S.W.G., the same methods are employed as with the main fuselage section.

Engine Mounting

In common with those of most British aircraft, the Spitfire engine mounting is mainly a tubular structure, although it is strengthened torsionally by the inclusion of a frame, resembling a fuselage bulkhead, which forms the central transverse member of the mounting. This frame is built as a separate sub-assembly. The main bearers consist of two cranked tubes extending from the front mounting block through the frame to the bottom mountings fittings on frame 5. Tubes for this portion of the mounting are received from the manufacturers ready bent and are finally set to the correct angle in the press.

Before the main assembly stage is reached the engine mounting blocks are fitted to the tubes and the attachment gusset plates are riveted up. Plug ends are also riveted in place at the rear ends of the tubes and in this form the main bearers constitute a

Fig. 166 —The separate jig for drilling attachment holes for the tailplane root.

sub-assembly of the complete engine mounting. A similar procedure is adopted with the other tubular members, which are cut to length and fitted with plug ends before being brought to the main assembly jig. Steel liners are inserted into the tubes and riveted through at the joints between the members.

Assembly of the mounting as a structure is done in the inverted position in the jig, which provides location points for the top and bottom fuselage pick-ups and for the forward and rear engine mountings. The frame is located on the rear engine mounting and the top bearer tubes, in two sections, are located at the rear on dummy top fuselage fittings and at the front on the forward engine mounting block. The joint between the tubes and the frame at the rear engine mounting is completed on the jig.

Assembly of the main cranked tubes is effected by threading them through the frame and picking up dummy bottom fuselage fittings at the rear with detachable locating pins. Riveting of the front end to the gusset plate on the forward engine mounting and to the attachment angles on the frame is then completed and the remaining stay tubes and members are assembled.

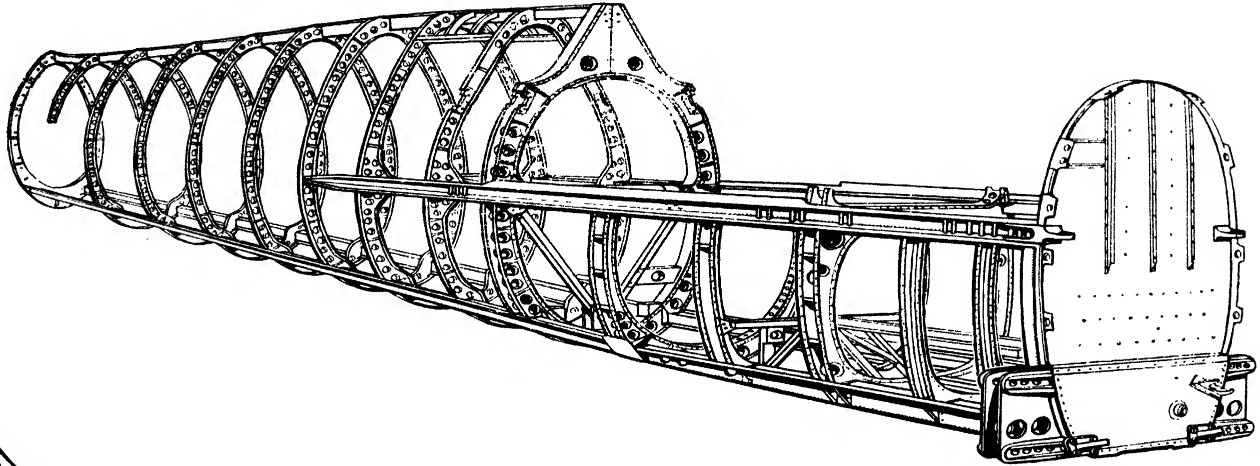
Tailplane

In plan view, the combined tailplane and elevator surfaces of the Spitfire closely resemble, on a smaller scale, the elliptical shape of the main planes. With the tailplane, however, the deeper elliptical curve forms the leading-edge. Like the rear fuselage sections, these units are also built in paired-up fixtures, one of which is illustrated in Fig. 164. The working platform of the fixture which carries the elevator-hinge locations is a length of heavy channel-section steel mounted slightly below bench height on three cast-iron columns. The framework of the fixture is all utilitarian, in the sense that each member carries jig locations, and consists of rolled steel end and centre columns of I-section attached to the platform by cast-iron angle brackets and connected at the top by inclined cross-members of channel section.

Fig. 167.—Checking the incidence of the tailplane.

The tailplane is a two-spar unit and the design does not call for special comment. Box construction is used for the main or forward spar, which comprises two channels, two flat web-plates and two angles on the front web-plate for the attachment of the skin. Sheet-metal ribs with flanged lightening holes are used throughout and have one unusual feature. Only one side is flanged for the attachment of the skin. The other side is instead slightly lipped and has, bolted to the opposite face of the web, a strip of spruce shaped to the curve of the rib. This arrangement is adopted to simplify the fitting of the skin. When the panels have been riveted to one side of the

Fig. 168.—
Details of the monocoque section of the fuselage.



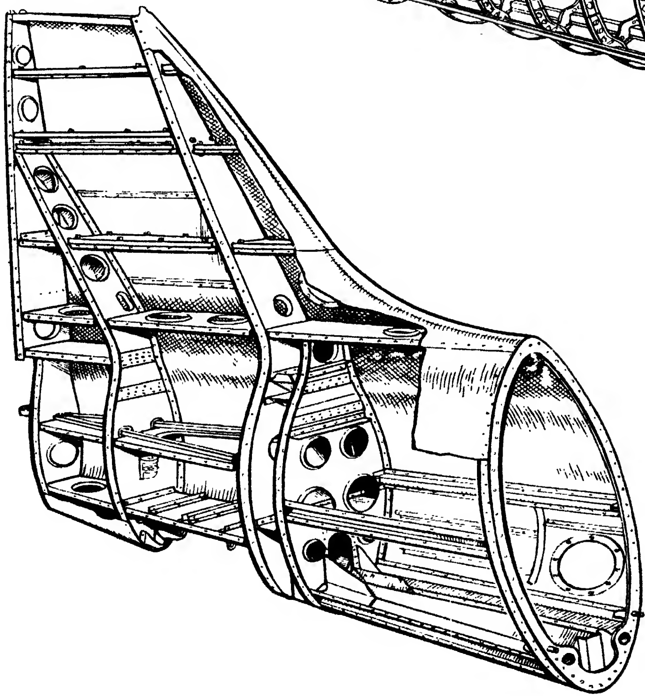


Fig. 169 (left).—
Details of the rear fuselage structure.

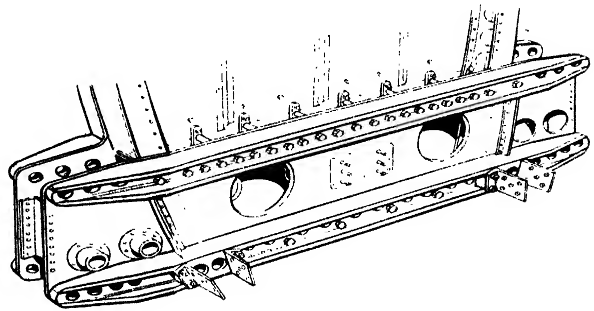


Fig. 170 (right).—
Rear view of the bottom portion of frame 5 showing the stub spars for attachment of the main planes.

tailplane, it is impossible to obtain access to the interior for "holding-up" to rivet the second side skin. Wood screws are used, therefore, inserted through the attachment holes and driven home into the spruce strip.

Before it reaches the fixture, the components of the tailplane front spar are assembled and drilled in a separate jig, after which they are removed, burred and assembled on the bench. The rear spar is a simple channel member carrying the elevator hinges.

Main Fixture

Assembly in the main fixture follows the usual sequence, all pick-up points being located positively by fittings on the fixture to give interchangeability between assemblies. The rear spar is located by the hinge fittings on the platform and by the rear fuselage attachment points at its root end. On this fixture locations for both spars are taken from a cast-iron bracket bolted to the centre column. In addition to the holes at the root, the front box-spar is also positioned at the tip on a tooling hole in the rear web, by a location suspended from the top member of the fixture.

Interspar ribs are positioned by attachment angles on the rear spar, drilled from them and riveted up. Interspar and nose ribs are attached to both sides of the main spar by bolts which pass completely through. Distance tubes round the bolts give internal support to the spar webs. At their tips the nose ribs are clamped by sliding locations mounted on the top member of the fixture.

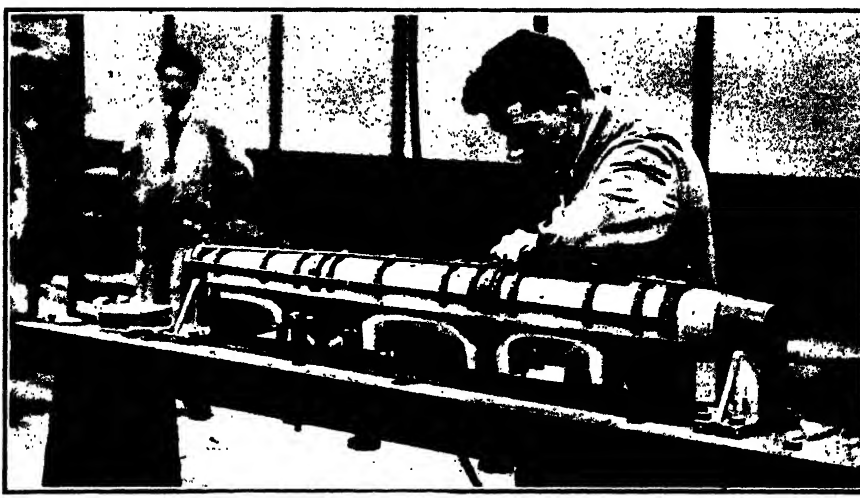


Fig. 171.—*Drilling the nose-skin for the rudder through a cage-type jig.*

At the outboard tip the tailplane is cut away to give clearance for the elevator balance, and the tailplane structure terminates here in an inclined rib attached at its root to the rear spar. As the working clearance is relatively small, owing to the proximity of the elevator, it is necessary to locate this rib accurately at the top, and this is done by pinning it through the web to a bracket on the end column.

Skin Plating

The skin plating of 24 S.W.G. Alclad is made in one piece for each top and bottom surface. These sections are formed in the press, and are jig-drilled with their L-section stiffeners. At the main fixture the stiffeners are assembled to the skins on lines parallel to and midway between the ribs. The rivet holes in the skin are opened out to full size by cramping the sections in place and drilling through from the rib flanges.

Around the leading-edge the skin is joggled to receive a nosing strip, which joins the two sections, and is seen in its drill jig in Fig. 165. This jig consists of curved

1 inch steel strips arranged to give a V location for the nosing, which is held in place by a series of latch clamps. Bushes are mounted in each strip, the nosing being drilled on one side for attachment by rivets to the skin and on the other for 4B.A. screws. This arrangement has the same object as the spruce strips on the ribs: attachment by screws on the second side, when the first surface skin has been riveted on. The screws engage a series of anchor nuts riveted to the underside of the second side skin. Actually, the nosing is applied to the first skin before operations are commenced on the second side of the tailplane.

The root fairing between the tailplane and the fin is made in three sections of 16 S.W.G. sheet, one for the leading-edge nose and one for each surface. The nose portion is hand-formed over a block, but the other two sections are pressings. These sections are cramped in place on a second jig, and drilled through from the skin. They are also drilled for attachment to the fin and taken off for press-countersinking. Butt straps are used to connect the three sections.

Finished tailplanes and rear fuselage sections are assembled as a unit in readiness for final assembly. Tailplane incidence is checked with the complete unit supported on a stand in a position corresponding with the horizontal flying attitude of the aircraft. Clinometer readings are taken at two points on each tailplane surface at specified distances from the centre line of the aircraft. Actually the tailplane should have zero incidence in this position. Each tailplane surface is attached at six points on its front spar and at four points on its rear spar to the rear fuselage.

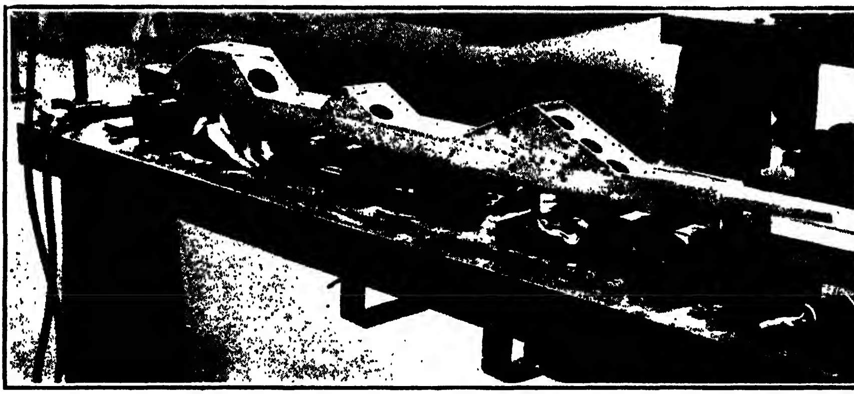


Fig. 172.—The D-section rudder spar in its assembly fixture.

Elevator and Rudder

As far as type of construction is concerned, the elevator and rudder surfaces are identical, the only differences between the units being those of size and shape. Similar jigs and procedure are used in the manufacture of each, and a description of the manufacture of one will serve for both. In principle, the construction is somewhat reminiscent of the main plane, being based upon a leading-edge of D-section which gives the structure its strength. There is no rear spar, the ribs, which are attached to the upright of the D-section, extending back to the trailing-edge. They are of lattice type assembled on the bench from pre-cut lengths of ¼ inch diameter duralumin tube, connected by small pressed-out, "wrapped-round" gusset plates and secured by tubular rivets. The horn balance is a small sub-assembly made in a separate fixture, and the heel or base of the rudder is completed by a curved, flanged pressing between the trailing-edge tube and the bottom of the leading-edge section. Apart from the leading-edge and the horn balance, both rudder and elevator are fabric-covered.

Leading-edge

The leading-edge is particularly interesting. It comprises two main parts, a U-section nose-skin and a channel-section spar of flanged sheet metal, though it would perhaps be better to regard the entire leading-edge as a D-section box spar, in which lightness is combined with strength to a remarkable degree.

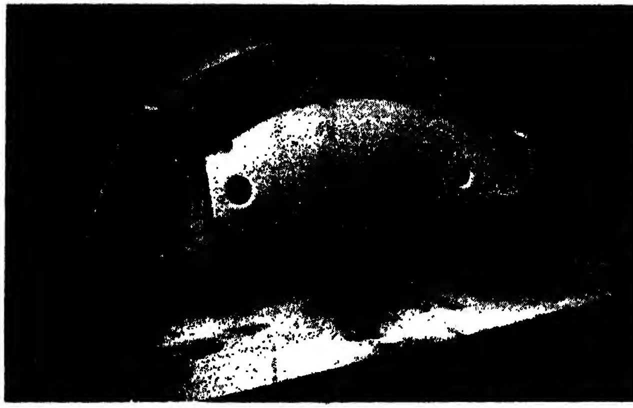


Fig. 173.
The rudder horn balance.

Fig. 174.
Part of an elevator in the assembly fixture.

Leading-edge assembly begins with the drilling of the nose-skin on the jig. The skin has already been formed to its U-section by which it is located for drilling on a Meehanite form block. Four tooling holes in the curve of the nose determine its longitudinal position, and it is clamped along the sides. A cage type of drill jig is used, built up from steel strip and clamped by studs projecting through the tooling hole locations. Smaller cages of the same type serve as templates for marking out

the hinge apertures in the nose and as jigs for drilling holes round the apertures. The clamping plates at the side are also shaped for use as templates in marking out the pointed projections at the rear of the nose-skin. Similar drill plates are used on a second jig of the same type for drilling the spar attachment holes and those along the rear edges of the skin.

After being removed from this jig, the nosing is trimmed to shape and the hinge apertures are cut out. It is then transferred to the one shown in Fig. 172, where it is located in felt-lined cradles.

In this jig D-shaped internal diaphragms or stiffeners are assembled inside the nosing and riveted up. Fabric patches attached to the diaphragms forming the boundaries of the hinge apertures provide anchorages for the covering, which is later applied over the whole surface.

The spar channel is next inserted between the edges of the nose skin and located by the hinge fittings on the platform of the jig. It is then riveted to the nose diaphragms and through its side flanges to the skin. Finally, the angular diaphragms are assembled

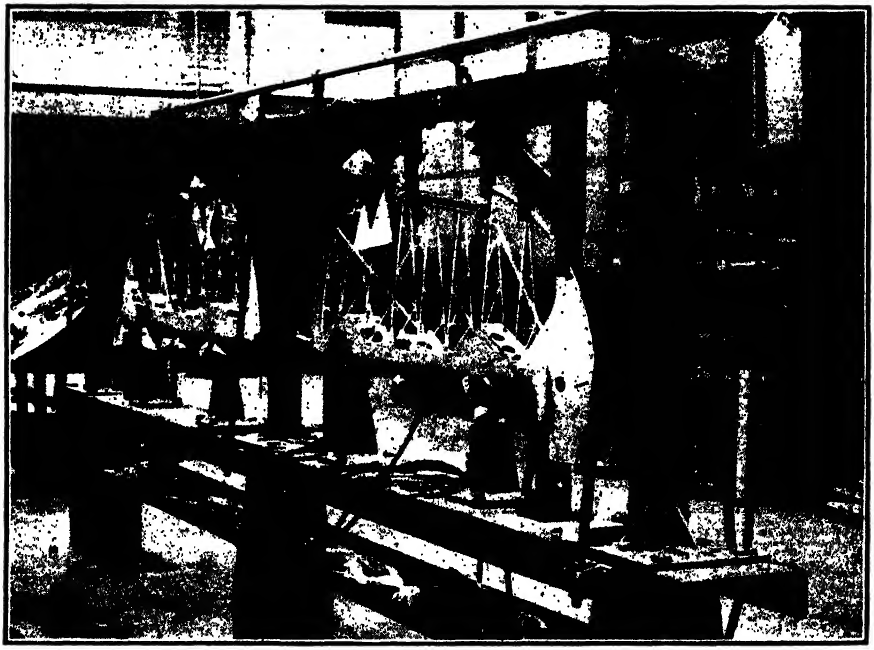


Fig. 175.—Two rudder units in their main assembly fixtures.

along the edges of the pointed projections and riveted up. The flanges of all these internal members are drilled from the nosing and removed for countersinking before being flush-riveted.

Rib fittings are also mounted on the rear face of the spar. A contour strip on the platform of the jig is used to check the nosing for tailplane clearance.

Final assembly of the complete structure is done in fixtures of the type illustrated in Fig. 174. These are very similar in construction and principle to those used for the tailplane. The leading-edge is located by means of the hinge fittings on the spar and the lattice ribs are assembled to the fittings on the rear face. At the tips the ribs are located by forked fittings suspended from the top member of the jig. These fittings also locate the streamline-section tube of the trailing-edge. Two lugs, formed integrally with the gusset plates used at the rib tips, embrace the trailing-edge tube and are attached to it by single rivets.

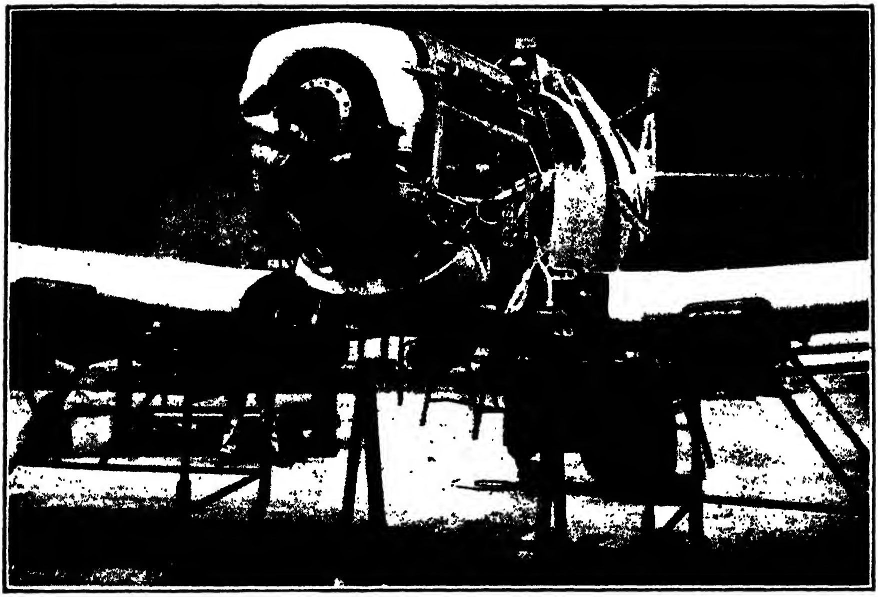


Fig. 176.—The wings—in cradles—in readiness for bolting up.

Fig. 177.—An undercarriage actuation test.

Locations are also mounted on the top member of the fixture for the trimmer boundary channel and the ribs forming the ends of the trimmer gap. These ribs are located by the trimmer hinge fittings at their trailing tips and the boundary channel by a rod between the two rib locations. At the base of the rudder the heel section is riveted between the trailing-edge tube and the leading-edge, a dead stop on the central columns governing the overall length of the rudder. Diagonal stay-tubes are also riveted between the spar, the trimmer gap and the trailing-edge.

Another small unit, also positioned by a location on the top member of the fixture, is the rearward identification lamp socket and its fairing. This is fitted between two sections of the trailing-edge and one of the stay tubes. Fabric patches are assembled beneath this unit and the trimmer hinges to provide further anchorages for the fabric covering.

Horn Balance Unit

Fig. 173 shows the horn balance in its assembly fixture. This section consists of three flanged, sheet-metal ribs and the section of the trailing-edge tube which extends from the balance weight itself to the identification lamp fairing. Assembly is a simple matter. The ribs are located against the sides of cast-iron brackets, which have vees cut in the tips to locate the trailing-edge tube. Four V-clamps hold the tube in place. Two of the rib tips are split, and the lugs which embrace the tube are attached by a single rivet. On the third rib, on which the balance weight is also mounted, the tube is attached to a small fitting on the web. The rib flanges are drilled from the skin panels, which are then tacked in position and riveted before the balance is placed in the main fixture for assembly with the rudder unit.

At its base the horn balance section is completed by a rib extending from the trailing-edge of the rudder to the extreme forward tip of the balance. In the main fixture this rib is accurately positioned for fin clearance against a vertical bracket on the fixture platform by one of the balance weight attachment holes in the web. The spar channel

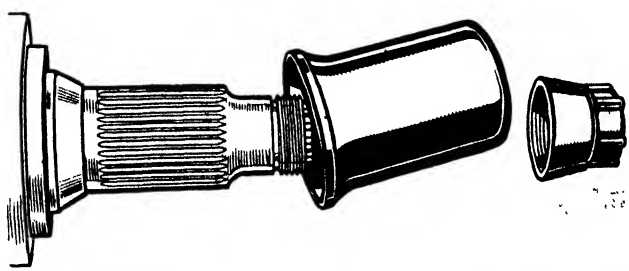


Fig. 178.—The airscrew shaft of the engine, protected from damage during final assembly by a cap.

flanges are drilled in the fixture from the skin of the horn balance unit, which is also located by a sliding vee mounted on the top cross-member. The finished structure is removed from the fixture and covered and doped in the usual way. A lead weight mounted in the extreme forward tip forms the actual balance and is adjusted to suit individual assemblies. Finished units are statically balanced about the hinge centres.

Final Assembly

As with other aircraft Spitfire final assembly follows a definite sequence, but this can be varied to some extent to suit immediate requirements. Actually, the initial stages are mainly concerned with the fuselage—installation of wiring and plumbing—and are usually referred to as intermediate assembly.

During this stage, the fuselage is supported on the two jacking points in the base of frame 5 and in a cradle under the rear at about frame 18. As the machine at this stage is nose-heavy it is held down near the tail by a canvas loop, which completely encircles the fuselage, just forward of the fin, and is secured to an anchor ring set into the concrete floor. Early in the intermediate stage, the tubular engine mounting

is bolted up to the front of frame 5 and the stern portion of the fuselage with elevators and rudder complete is assembled at the rear on frame 19. Among the first items of equipment to be installed are the undercarriage operating jacks, fitted to their anchorage at the bottom of frame 5. These are followed by the mounting of the dashboard with a majority of the instruments as a sub-assembly in the cockpit and the connection of its associated wiring which at this stage is not taken farther. The Perspex sliding hood and the screen with its bullet-resisting sighting panel are also assembled.

Another sub-assembly fitted at this point is the control column and rudder bar in the cockpit. Connection of the controls to the tail surfaces follows the installation of this unit. Other items assembled early in this stage include the aerial mast, a metal-enclosed unit of synthetic material, and the upward identification lamp and blister. All these are mounted in the split dorsal longeron of the fuselage. The wireless access door behind the cockpit is also fitted.

A good example of the manner in which war requirements have been met is afforded by the plastic pilot's seat which replaces the built-up sheet metal assembly previously employed. Quicker production and conservation of metal are accompanied by a considerable saving in weight, which permits the essential addition of armour-plate for the protection of the pilot to be made without undue increase in the overall weight.

With the engine mounting in position a commencement can be made with the installation of the associated equipment. The oil tank is assembled on the lower tubes under the mounting, oil and petrol piping and other plumbing is fitted and the engine control connections are brought through from the cockpit. Another item fitted at this stage on the port side of the engine mounting is the resistance box for the interrupter circuit.

Engine Installation

At this stage the engine itself is installed. It is a Rolls-Royce Merlin XLV, and is brought to the assembly, complete with glycol header-tank, on an overhead conveyor. The engine is supported on four blocks and requires careful handling, while being lowered to prevent the supercharger at the rear from fouling the engine mounting and frame 5. When it has been bolted down, the controls and all plumbing to the various services, compressed air and hydraulic cooling system are installed and connected up.

Cowling formers and rails are next fitted, these being supported in an ingenious way, partly on frame 5, on the oil tank and exhaust manifolds and on the front ring, a flanged circular frame on the front of the airscrew-shaft cover. After this petrol tanks are installed in the bay between the engine and the cockpit.

Final assembly proper commences with the attachment of the wings. These are brought to the assembly by wheeled trolleys on which they are tilted to the approximate dihedral angle with the spar attachments at correct height for bolting directly to frame 5. In Fig. 176 they are shown in position just prior to being connected up. After this, fillet formers and the root fillets themselves are fitted between the wing and the fuselage.

Heating and control systems are next completed, after which a series of tests is carried out on the oil, air and hydraulic systems and the electrical circuits. Undercarriage actuation is tested with a portable rig at a pressure of 1,200 lbs. sq. inch, the operation being shown in progress in Fig. 177. A portable rig is also used for testing the electrical circuits.

The three-bladed constant-speed airscrew, which may be either of Rotol or de Havilland type, is assembled on the engine shaft during this stage. After a final check, the machine is tanked up, the engine cowling panels are fitted and the aircraft is wheeled out on to the apron for an engine test run, which includes a period at full throttle.

One of the last operations in the shops is the mounting of the cannon and the harmonisation of the guns.

This is effected by aligning each gun with its target on a marked board set up at a distance of 50 yards from the aircraft. Finished aircraft are towed to the flight shed, where they are given a further complete inspection by both works and A.I.D. personnel prior to flight testing.

BLACKBURN STRESSED WING CONSTRUCTION

Tubular Booms and Stringers with Solid Riveting

ONE of the interesting features of the construction of the Blackburn " Botha " is the first practical application of a system of tubular construction for stressed skin metal wings. After considerable development work the initial difficulties of the system have been overcome and the new method affords a number of worth-while advantages. The method is based upon the employment of tubes for the wing spar booms and the intermediate stringers which take the place of the more usual Z or channel section stringers. The shell plating is riveted to the girders and stringers, all rivets being of the solid type, inserted and riveted from the outside of the wing. A comparison of the new method with that used in the construction of the wings of the Blackburn " Skua," which were of more conventional design, is given in Fig. 179.

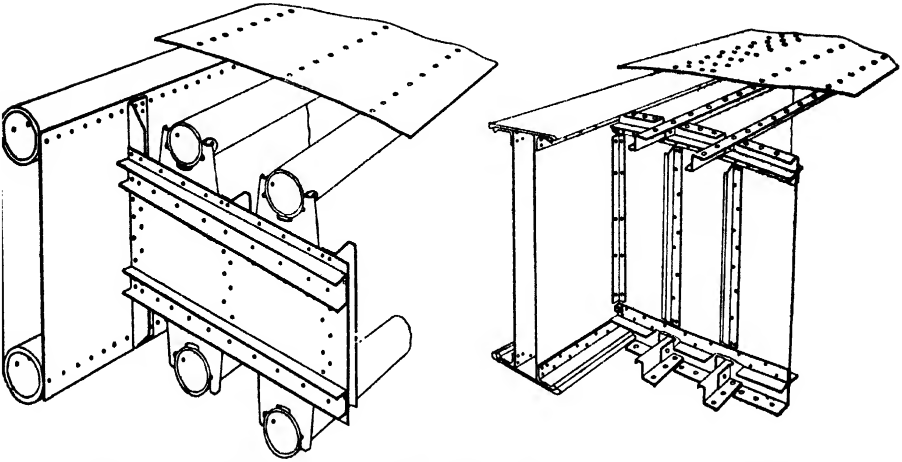


Fig. 179.—A comparison of the relatively simple tubular construction of Blackburn Botha wing, and that of Blackburn Skua and Roc.

" Skua " Design

In the earlier " Skua " design the spars were built up from six extruded sections, three to each boom, and from webs of flat plate. To match the contour of the wing four extruded L-sections of the boom required different dies for their manufacture. Apart from this complication, difficulty was also experienced owing to the manufacturing limits required for " unstable " extruded sections of this type, which permit a variation on angles of $\pm 2°$. Cases have occurred where a front spar angle has been $+ 2°$, and a rear spar angle $- 2°$. If the skin were attached directly to these angles the result would be deep waves in the skin surface. With the tubular construction, the skin plating is always tangential to the boom, irrespective of its position relative to the contour of the wing.

Stringer and Girder Boom

In most types of stressed skin construction the dimensions of the girders and stringers are determined by bending loads, and the gauge of the skin plating by torsion. Consequently, the lightest construction is the one employing stringer and girder booms of sections which develop a high ratio of proof stress to cross-sectional area. A tube, being of stable section, is ideal in this respect, and structural tests have confirmed that when made in DTD 220A full advantage can be taken of the specified proof stress of 21 tons/sq. inch. With a channel, lipped angle, or one of the more conventional extruded sections, as used in the "Skua," it is seldom possible to work to a stress higher than 14 to 15 tons/sq. inch. Also, as the bending moments throughout the wing structure are progressively increased from the tip inboard to the root, it is necessary, if uniform stresses are to be obtained, to increase the sectional area of the spar booms progressively in this direction. This is very difficult with extruded sections, but is

relatively simple in tubes which can be reduced in gauge by drawing. Such a process, developed on a production basis by the Reynolds Tube Co., Ltd., for Blackburn Aircraft, permits the outside diameter of the tube to be kept constant, while the wall thickness is varied to conform to the loading conditions. Although it is rather more specialised than that of parallel tubes with constant wall thickness, the manufacture of these tapered tubes does not present serious difficulties.

Advantages of Tubular Construction

Two further advantages follow from the use of tubes. These as delivered from the manufacturers are finished and require no further machining. Firstly, the work of the machine shop is considerably reduced and special equipment, such as large spar-milling

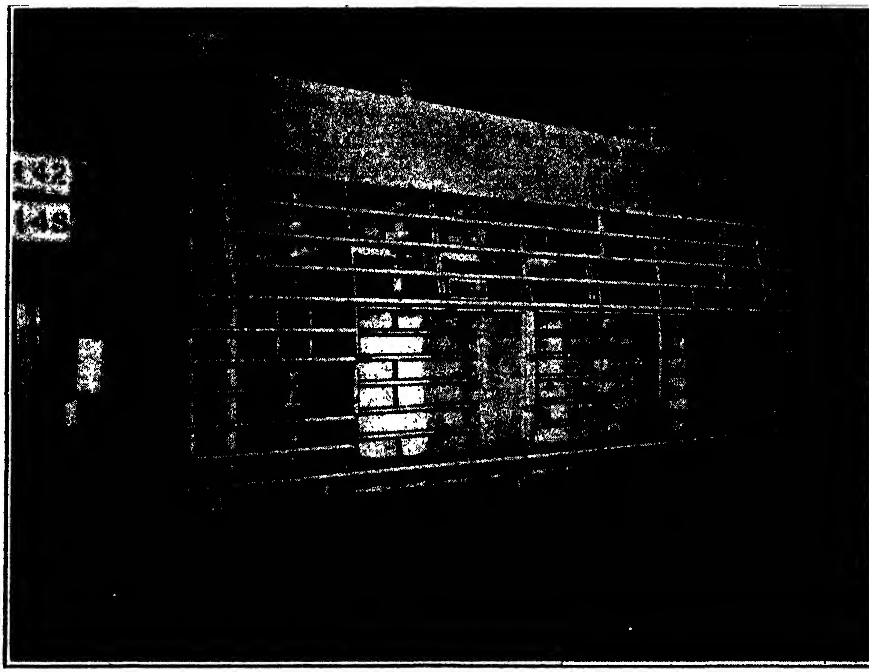


Fig. 180.—The complete centre plane structure in the main assembly jig.

machines, are not required. Also the saving in material is very considerable. The extent of this will be appreciated when it is realised that some extruded sections used for aircraft spar booms are machined to such an extent that the final component weighs only 40% of the original extrusion. On the "Botha" the weight of the booms and the spar stringers is 615 lbs. It may be assumed that if these were made from machined extrusions at least 55% would be removed by machining. On a contract for 1,000 aircraft this would involve 96 tons of metal cut to waste. Further, it is known from structural tests that the tubes develop a higher stress than extruded channels or angles, so that here again the cross-sectional area and weight of material involved is reduced very considerably by the employment of such a stable section. Finally, the elimination of machining operations reduces the number of gauges and process inspections to a minimum, and avoids the unnecessary handling of the material in the factory.

Simplicity of Riveting

The most striking advantage obtained by the use of tubular construction is the rapidity and simplicity of the riveting, all rivets being inserted and closed from the outside of the tubes. This method of external riveting is made possible by the use of

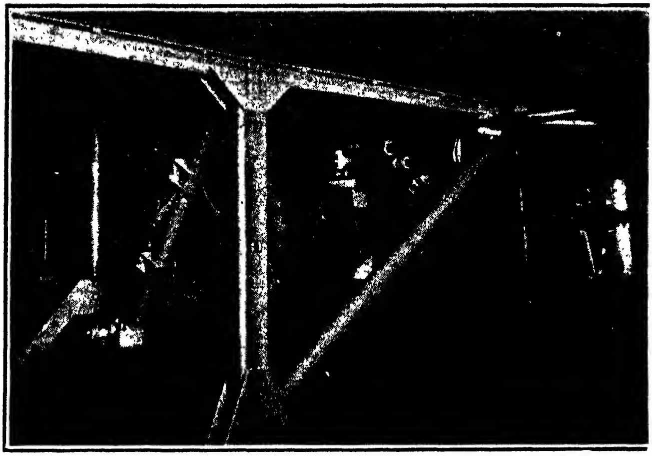


Fig. 181.—Construction of Botha main frames carrying centre plane attachment fittings.

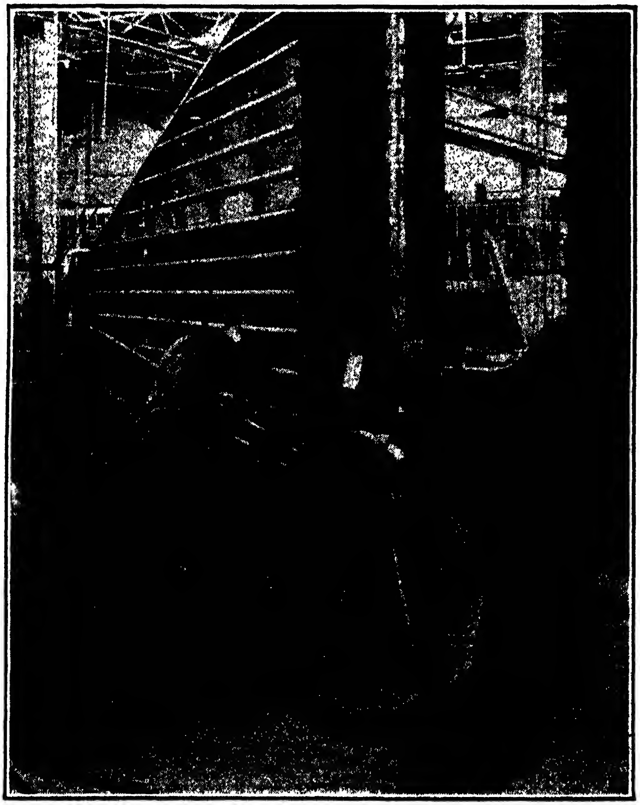


Fig. 182.—Riveting main ribs of Botha outer plane to tubular stringers.

Fig. 183.—Another view of the Botha fuselage interior.

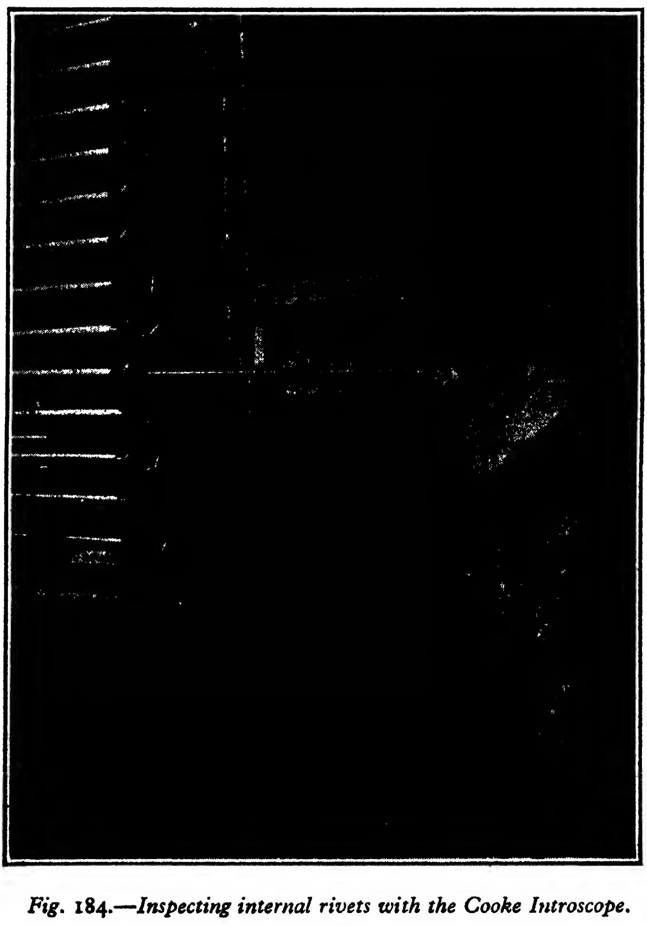


Fig. 184.—Inspecting internal rivets with the Cooke Introscope.

a special type of dolly, illustrated in Figs. 182 and 185. To the dolly head proper is coupled a follower or guide similar in construction to the dolly head, except that square slots are cut in the opposite flats. These slots locate on the heads of the rivets already formed, as the dolly is moved along the tube. The follower guide is coupled to the dolly head by pins, which prevent the dolly from rotating in the tube, but permit freedom of movement for riveting. A solid portion precedes the sprung section of the dolly and serves as a pilot. The dolly is the only special equipment required, an ordinary pneumatic riveting tool being applied externally to the pre-formed head of the rivet which may be either countersunk or round head. The internal head of the rivet is formed by the reaction of the dolly as the pneumatic hammer on the rivet causes it to vibrate and develop a hammering action on the inner end. The body of the dolly is made in two parts which slide upon dowel pins.

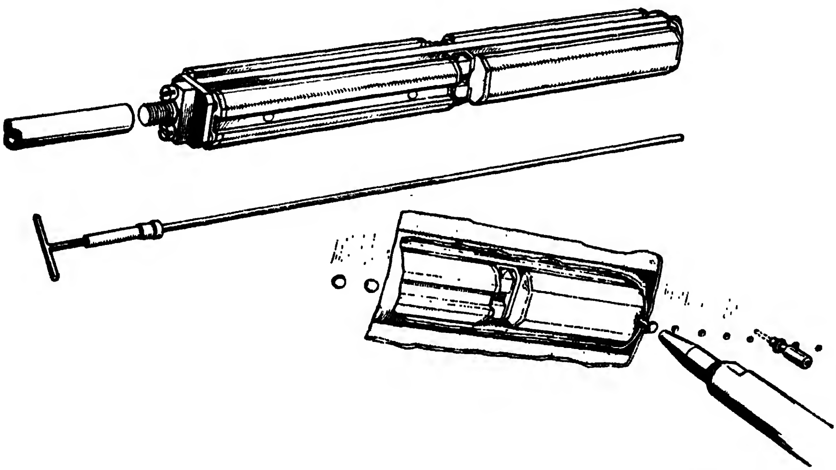


Fig. 185.—Special Spring Dolly developed for use with Blackburn system of external riveting ; the cutaway shows the dolly in use.

Special Dollies

In the "Botha" structure only two sizes of special dolly are required, one for the girder assembly and the other for the skin plating. This method of riveting is simple and certain in its procedure and can be performed by semi-skilled labour without any risk of bent shanks or deformed heads. The dolly is mounted on the end of a serving rod and is fed progressively into the tube. There is no need for precise location on any one rivet as the length of the dolly is considerably greater than the intervals between several rivets at normal pitch. It is, therefore, possible to proceed rapidly along the line of rivets from one end of the tubular member to the other. Interruptions for the changing of dollies, such as are necessitated in other forms of structure by corners and other positions difficult of access, are quite unnecessary. Moreover, the dolly requires no holding up, and, therefore, does not occasion fatigue to the operator.

Use of Cooke Introscope

For inspection of the internal rivet head, the Blackburn Company have developed a special type of Introscope. This is shown in use in Fig. 184, and permits each rivet head to be examined individually. Such detailed inspection has, however, been found unnecessary owing to the accuracy and uniformity of the riveting produced by the special dolly. Internal inspection, therefore, has been reduced to the selection of a few rivets in each member, which again represents a considerable saving in time.

Root End Fittings

The root end fittings are of simple construction consisting of simple lugs which mate with fork ends, while the system provides an excellent means of jig location. In the case of a machine with folding wings, the method of construction offers further advantages over the built-up girder method of construction, as the tubular booms may be provided with forged fittings to take the hinge loads.

Fig. 186.—Riveting skin plating to the centre plane. The gang of men shown are allowed 11 hours to complete the whole unit.

QUANTITY PRODUCTION OF LIGHT TWIN-ENGINED AIRCRAFT

THE BRISTOL BLENHEIM

Principle of Quantity Production

THE secret of speedy, and therefore large-scale, production is to build aircraft in components, each as small as possible and completed as far as possible before it is joined with other components in the next larger assembly. By adopting this as a guiding principle, the greatest possible number of men are enabled to work simultaneously on the one machine, so producing it in the shortest possible time.

This principle has been carried out in the design of the Blenheim, for it consists of a series of main assemblies which are finally brought together and quickly joined to make the complete airframe. These main assemblies are the front fuselage, the rear fuselage, the stern section of the fuselage with its empennage, the centre plane (extending to just outside the two engine nacelles), the two main planes, and the undercarriage.

The above principle has been followed by insisting that as much work as possible shall be done in the pre-assembly stages. Electric wiring and control cables are all installed as soon as possible, so that only a minimum of this work remains to be done when the machine takes shape in the final assembly in the erecting hall, where working space round it is decidedly limited.

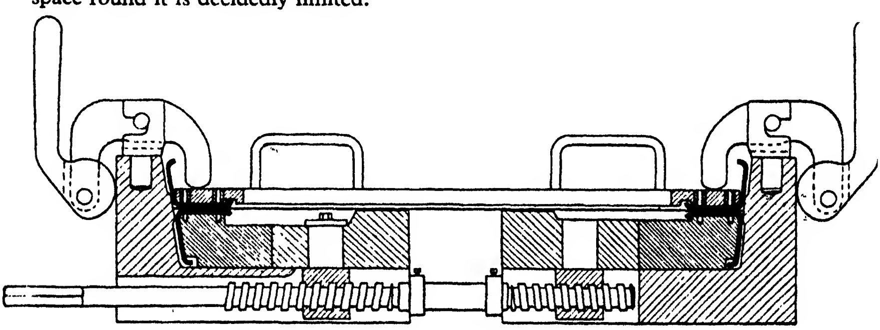


Fig. 187.—Cross-section of the main plane spar-drilling jig.

The wing of the Blenheim is of two-spar stressed-skin construction with sheet metal ribs running fore and aft. Both main planes and centre plane spars are of the same form, that is, a single flat web of Alclad (D.T.D.390) to which steel angles (D.T.D.138) are riveted to form the flanges. Supporting the flanges of the angles are curved-section " cornices." Mild steel rivets are used. To conform to the aerofoil section, the flanges of the angles are not at right angles to the web. Webs for the straight-taper spars are cut very simply from sheet Alclad. A single diagonal cut is taken across a rectangular sheet, so forming two blanks and producing a front and a rear web from the same sheet. Each blank is placed on a trimming table and a hinged steel trimming template placed in position upon it. Desoutter electric shears are used with the template to shape the blank to exact size. The flange angles and " cornices " are rolled from strip steel. The web, together with the flange angles, next goes to the spar drilling jigs, which are among the most interesting pieces of tooling equipment in the factory.

Spar-Drilling Jigs

To ensure rapid production the drilling jigs for the spars have been made with great attention to detail and convenience. The bed of the jig is a long, cast-iron structure, accurately machined, in which the web plate and the flange angles are laid out in position. A right- and left-hand thread on a screw actuates parts of the jig which hold the lower flange angles in position by forcing them against the correctly sloping sides of the jig. Several of these screws are connected together by chains and sprocket drive.

The spar web and the other pair of flange angles are then laid in position with the drilling plate on top of them in order to hold them rigidly in position. The drilling plate is provided with handles to facilitate lifting it into and out of the jig. Clamps on the side of the jig hold the drill plate in position by exerting downward pressure on it.

Drilling is performed by a series of Asquith six-spindle drilling heads. These are traversed by hand on a cast-iron track above and behind the drilling jig. There are, of course, several jigs for main plane and centre spar drilling, and the equipment includes four Asquith drilling machines for centre plane and five machines for main plane spars.

Centre spars are also drilled in the same manner, using a drilling jig of the same type. In this case, however, the drill plates are hinged on the centre line of the spar to allow assembly.

After drilling, the drill plates are removed and Chobert tubular service rivets are inserted at intervals so that the whole assembly is held together. After it has been removed from the jig all burrs are removed from the spar, which is then placed in a riveting fixture of the trunnion type. This holds the spar so that the web is in the

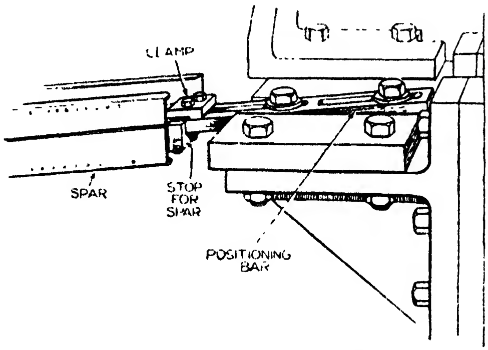


Fig. 188.—Details of the adjustable end fitting in which the tip end of the spar is held in the main plane assembly jig.

horizontal plane. All the rivets through the holes are inserted by means of two traversing E.M.B. squeeze riveting machines, one working on each flange of the spar. These machines are foot operated and leave the man's hands free to attend to the traversing. The air pressure can be adjusted to suit the rivet being closed, both stainless and mild steel types being used. Permanent rivets replace those previously inserted for service purposes, which are drilled out.

At this stage the steel web stiffeners and the intermediate Alclad stiffeners for the attachment of the ribs are riveted on.

After this operation the spar goes to another riveting jig for the assembly of the pre-drilled " cornices." This ensures that the inclination of the flange angles is correct. Holes through the web are drilled from the cornice and riveted with mild steel rivets, except at the root ends, where stainless steel rivets are employed for greater strength. This riveting is done with an air gun, the dolly being held up by hand. Owing to the varying inclination of the flange angles, a separate jig is used for each flange of the spar.

The predrilled steel channels are placed in position on the " cornices," and the " cornices " and angles are drilled by means of a sliding drill head which traverses the length of the fixture on a guide rail. Riveting of the channels is performed in a trunnion fixture, alternate rivets only being put in as the other holes are left for the skin-attachment rivets to be placed during wing assembly. Bostik is then applied to fill all spaces in which moisture might lodge.

End Fittings

Horizontal pin joints form the connection between the centre plane and main plane spars. High-tensile steel fittings are attached to each spar flange to accommodate the pins. The pair of fittings for each flange is lined up by a pin inserted through the main holes and with one of the horizontal bolt holes drilled 1/84 inch undersize. The

other holes are then drilled through both fittings and the spar flange and reamed to a Newall B fit. Next the bolts are fitted and pinned to prevent loosening, this operation being performed on all the spar fittings.

Holes for the vertical bolts are then jig drilled and reamed to Newall B fits. These bolts are also peened over.

Particularly important operations are the milling and reaming of the spar end fittings. These operations are performed on special machines designed by Rootes and made by G. Hey & Co., Ltd. The four faces of each flange fitting are finish-milled simultaneously, so giving the required gap between the faces. The spar end is held on a fixed table with the web horizontal, and the milling cutters are traversed towards the spar. Tolerances on this operation are very fine to ensure a tight joint and the correct dihedral angle.

Two reamers operate simultaneously on the fittings of both spar flanges, and are brought into position by a traversing movement at right angles to the length of the spar. A steel-bushed bar jig is used to guide the reamers. Two reaming operations are required to open out the holes which are finally hand-reamed to receive a press-fit steel bush. This can be replaced when wear develops after a period of service. After being painted by spray gun in an adjacent spraying booth, the spars go on to the roller storing racks for drying purposes and are then ready for assembly.

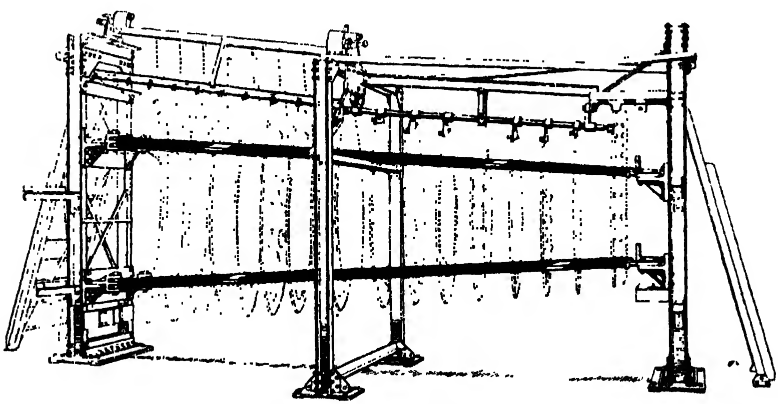


Fig. 189.—*The structure of the main plane assembly jig. The spars are held at the root end by pins through the end fittings and at the other end by an adjustable fitting which is seen in Fig.*

Tailplane Spars

The method of manufacture of tailplane spars closely resembles that of the centre and main plane spars. Overhead manually operated clamps at intervals of approximately 6 inches are used to hold the spar components in position during the drilling operation.

Main Plane Assembly

Orthodox two-spar construction is used for the Blenheim main plane. The ribs are made in three parts, composed of inter-spar, nose and tail. They are produced on the press from Alclad sheet and are pierced with flanged lightening holes and strengthened by vertical stiffeners of top-hat section. Certain ribs, for example, those carrying aileron hinges and petrol tanks, have double webs connected by vertical members. Spanwise stringers, also of top-hat section, stiffen the skin by dividing it into smaller panels.

Elaborate vertical jigs of rolled steel angles, with the structure set into the concrete floor, have been built to allow wing assembly work to proceed with the utmost speed. The two spars are first set up in the jig and held at their root ends by pins through the attachment fittings. The attachment at the tip end is adjustable.

Nose rib sections are first riveted on, followed by the trailing ribs and the inter-spar ribs. The stringers are passed through slots in the ribs and attached at their ends only. Application of the skin commences with the top surface. This is flush-riveted

in position by orthodox methods, pneumatic drills and riveting guns being employed. At this stage the aileron controls and the electric wiring are installed and then the plating of the lower surface is commenced. Riveting proceeds from each end, holding-up being accomplished by reaching into the back of each sheet. Holding-up for the last sheet is done through inspection doors. The main plane is then ready for removal from the jig. After the wing tip has been fitted, the complete wing is bolted securely into a wheeled vertical stand for easy transport. It remains stored in this way until required for assembly in the erecting hall.

The centre plane is made in two sections, the trailing edge and rear spar being assembled first. Next, the front spar is set up in another jig, and the inter-spar ribs and the trailing-edge section are assembled to it. The nose section of the centre plane is not attached at this stage but is put on during the main assembly. Centre planes are also kept in vertical stands until required.

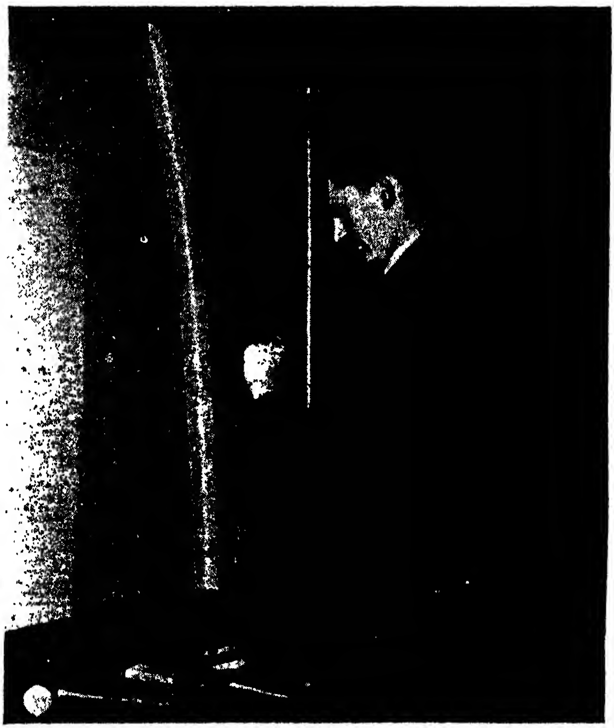


Fig. 190.—*After the plating has been applied to the tailplane, a local drilling jig is attached and the boundary angles for the attachment to the stern section are riveted on and drilled on the outstanding leg.*

Tailplane

The tailplane is metal covered, built up on two tapered spars of channel section. These are produced on the press from Alclad sheet. Alclad pressings are also used for the ribs. The tips are separate units, attached, and are assembled at a later stage by screws and Simmonds nuts.

Tailplane assembly jigs are of the familiar vertical type in which the two spars are mounted horizontally between two dummy end ribs of cast iron. The first operation consists of assembling the ribs to the spars. This is followed by the attachment of the spanwise stringers on one side only. Riveting of the skin is then performed on this side, after which the stringers and skin are fitted to the other side.

Fig. 191.—*The tailplane mounted in a turn-over stand for later assembly operations, such as the fitting of the trimming tab.*

Fig. 192.—*Making ready to offer up the tail unit to the rear fuselage in the E.H.*1 *stage of assembly.*

The final operation is to rivet on the angles which form the joint between tailplane and fuselage. The support for the rudder post is also drilled. Complete interchangeability for the fuselage attachment is ensured by the use of a loose cast-iron drilling jig fitted to the main tailplane jig.

The fin is also a metal-covered structure of Alclad built up on the stern post, which carries the rudder hinges, and the leading-edge spar. This component presents few difficulties, and does not offer many opportunities for novel methods in its construction.

It is joined to the tailplane by a vertical bracket and by a right-angled skin joint with angles. The angles for this joint are riveted to the fin and drilled ready to take the screws connecting it to the tailplane.

Control Surfaces

Ailerons, elevator and rudder all comprise a metal structure with fabric covering. As similar methods of construction are used for all, only the elevator will be described.

A tubular steel spar forms the basis of this unit. It is two inches in external dimeter, and tapers in thickness. Contrary to expectation, it is thicker at the outer end and thinner at the centre line of the fuselage. A tube tapering in thickness has been used to give greater wall thickness where this is required for strength, this being at the outboard hinge.

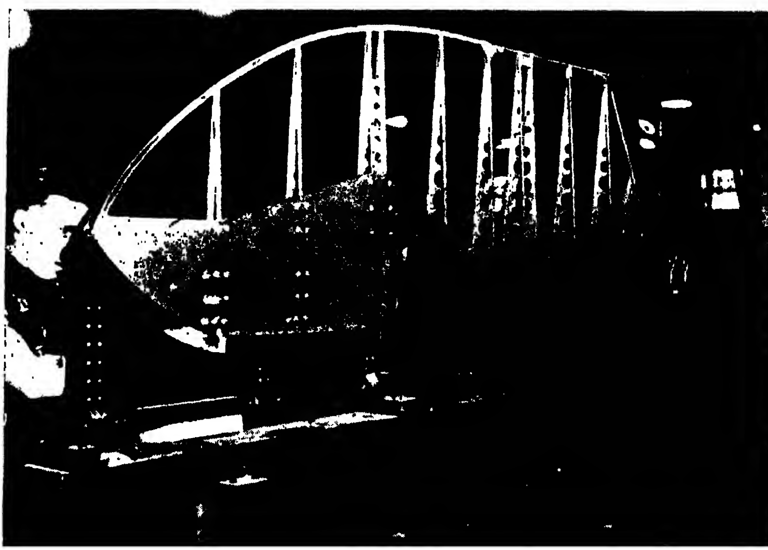


Fig. 193.—After being assembled in a vertical jig, the elevator is tested for clearances in an interchangeability jig.

Pressed Alclad ribs extend backward from the spar to the trailing edge, which is a small oval section extrusion of aluminium alloy. Though all the remainder of the surface is fabric covered, the aerodynamic part, which is at the outboard tip, is covered with Alclad sheet.

Each half of the elevator is assembled in a vertical jig which holds the two main members horizontally. The ribs are threaded on to the tubular spar, and the whole structure riveted together. After removal of the jig is tested for clearance in the interchangeability gauge. Any subsequent work, such as the fitting of the trimming tab, is done with the elevator set up in a stand of the turnover type. Application of the fabric is the final operation.

The above is typical of sub-assembly work. It presents no major difficulties, mainly due to the accurate tool-produced details and efficient jig design, both of which allow the work to proceed very rapidly.

Sub-Assemblies

The sub-assembly department is large enough to be regarded as a separate " factory." In this section are manufactured tailplanes, tailplane tips, wing tips, fins, rudders, elevators, centre plane nosings, ailerons, and the flying control assemblies for the cockpit. In addition to these main components, an enormous number of minor and sub-assemblies are made in this department. Oxy-acetylene welding, the bending and forming of all kinds of piping, brazing and soldering (both soft and silver) and pipe line testing are performed here.

In the welding section, the welder is sometimes supplied with duplicate jigs, one holding the job on which he is working and the other containing work cooling off or being set up for him. A toolmaker is employed for setting up and checking.

The coppersmiths' section is equipped with gas blowpipes and tube-bending apparatus. Resin is used for bending pipes of light material " Bendolite " for heavier gauge tubing. Steel tubing of certain gauges is bent on Hilmor bending machines.

The testing of unions and pipe line systems is part of the work of this section, and, to increase output, units can be tested in quantity, using tanks of fluid with pressures ranging from 15 to 1,500 lbs. per sq. inch.

Another section does all the cable splicing for control cables and the necessary proof-loading tests.

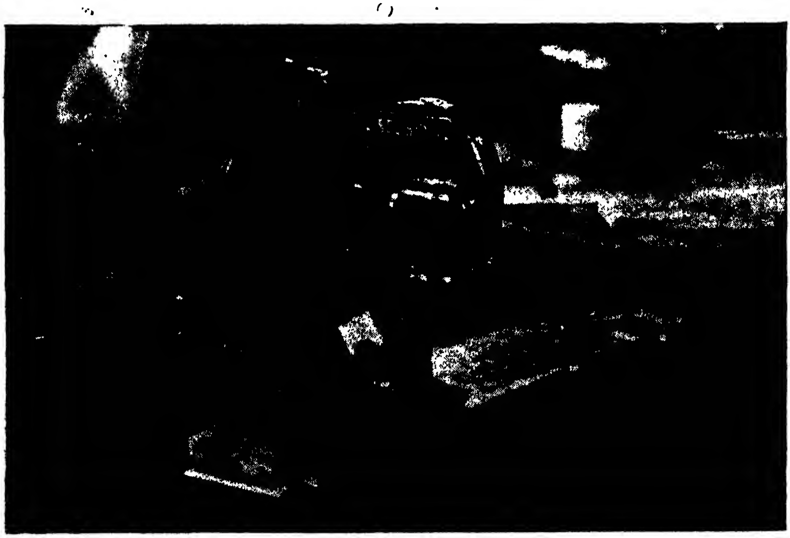


Fig. 194.—A Selson flanging machine at work on a flanged tailplane rib.

Drilling Equipment

The drilling equipment of the sub-assembly department is varied, and consists of Herbert, Pollard and Jones and Shipman drilling machines with single and double spindles.

Air drills include Desoutter Mighty Atoms, Desoutter 45 and 90° drillers, Power Vane drillers for heavier work, Desoutter and Armstrong piston chuck drills, Thor chuck drills and various Chicago pneumatic types. These are all of the " plug-in " type and pipe lines are fitted at every bench.

Batteries of riveting machines comprising electrically driven and self-feeding riveters, pneumatic Erco punch and riveting machines, Jackson horizontal riveters with large type yokes, Broomwade squeezers of the portable pedestal type, Aero and Thor portable vice squeezers, one-shot guns, and other foot-operated riveters. A hydraulic power press is used for expanding Oilite bushes.

A Broome and Wade compressor supplies the power necessary for the pressure test plant. Surface tables, 12 feet and 8 feet, are used for setting up tubular assemblies.

Rivets and Riveting

Many of the rivets used in the Blenheim are made in the Rootes factory, both steel and light alloy types being manufactured. A Waterbury Farrel machine produces 125 rivets per minute from the light alloy D.T.D.327. Three operations are involved: heading, shearing and ejecting.

A second machine, also Waterbury Farrel, is in use, and, though two strokes are required to form each head, it is capable of making 240 rivets per minute out of light alloy wire to Specification D.T.D.268.

To prevent age-hardening of rivets, the usual method of storing in a refrigerator after heat-treatment is employed. The rivets are immersed in methylated spirits, freezing point of which is below the temperature used, about −20°C. This prevents the rivets freezing into solid blocks, as frequently happened because of water vapour condensing on them. Such a happening would cause waste time.

Woodworking Shop

Though the Blenheim is an "all-metal" aeroplane, there are many small parts of it which are made of wood; for example, trailing edges made of laminated mahogany, parts of the flooring, doors, and numerous other small parts. The woodworking shop is well equipped, there being a bench section and a machine section, this latter occupying

Fig. 195.—After being completed on the jig the front fuselage unit is removed and mounted on a wheeled stand for the installation of equipment.

about one-third of the total area. There are two Visco dust-extraction plants, which work alternately with each other and draw sawdust and small wood pieces from each machine. Large-diameter overhead tubes carry the waste material away, and the plant outside the building sorts it into sawdust and wood waste of larger pieces.

Building Front Fuselage

At first sight, this jig on which the front fuselage is built seems to be extremely complicated. It is, however, an ingenious and orderly complication, and with it the front fuselages are constructed very quickly in the inverted position.

At the rear end is a vertical rolled steel framework which supports the eight main horizontal tubular members of the jig. These tubular members are of liberal section

to ensure rigidity and to enable them to stand up to the wear and tear entailed in the assembly of hundreds of fuselages on each jig. They extend along the length of the front fuselage and are " collected up " into one member which is supported at a single point immediately in front of the nose. From the tubular jig structure the various locating points extend outwards to grip the transverse frames and the bent tubular framework to which the transparent part of the nose is attached.

Provision is made for the insertion of two horizontal datum bars a little above ground level for use when periodically checking the jig. From these two bars, one at each side of the jig, vertical measurements to all the locating points can be made. The rear vertical framework of the jig is the datum for all horizontal checks. Frames of Z-section are all in the transverse plane, and to locate them exactly until the skin is finally riveted on, a temporary plate of about ¼ inch thickness is clamped to them to prevent any bending or movement between supporting points.

A framework of bent duralumin tubing carries the windscreen and transparent nose of the machine. The various tubular members forming the framework are bent to shape in the sub-assembly shop in bending tools of laminated wood. Many of the tubes require bending in more than one plane, and the shape of the tool is developed

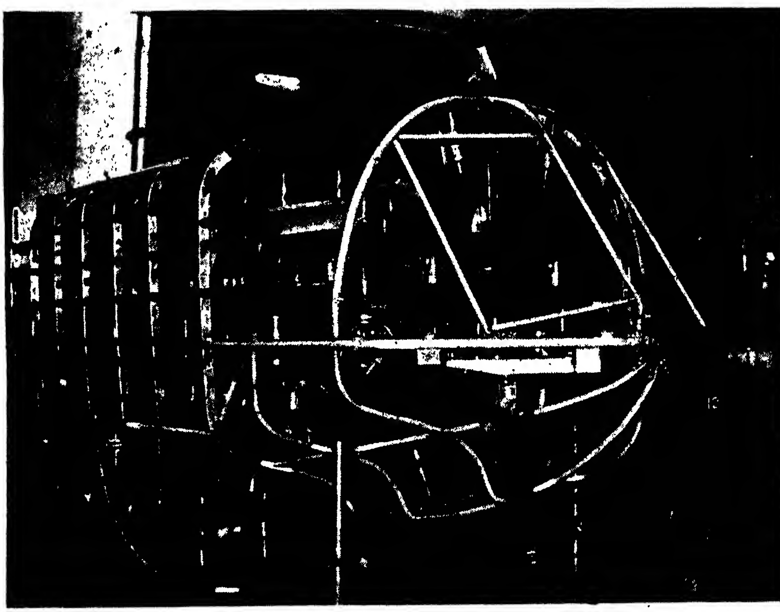


Fig. 196.—The front fuselage being assembled on its jig, in the inverted position.

by a process of trial and error in order to incorporate the correct allowance for " spring." After being bent on the tool, the tube is tried out for shape on an interchangeability gauge and returned for alteration if required. During bending, the tube is filled with the low melting point alloy Cerrobend, which supports the wall against collapse. Its high bismuth content keeps the melting point below the boiling point of water so that it can be very conveniently handled.

Location of Tubular Members

As much assembly work as possible is done on the tubing structure in the sub-assembly shop before it goes to the front fuselage jig. This is an application of the modern production practice of doing as much work as possible in the earlier stages of construction. The various parts are located in the jig by clips. At the end of an arm extending from the tubular framework is a block with a semi-circular cutout into which the tube fits. By means of a wing-nut, a small retaining piece of circular shape to conform to the tube is drawn up and clamps it tightly.

This jig holds all the skeleton members of the fuselage firmly and accurately while the component is being plated. Despite its many members, access is easily obtained to the interior. Plating of the fuselage is a straightforward process, the panels of skin being drilled back from the pre-drilled frames and stringers. The curved panels near the nose are wheeled to shape from D.T.D.213 material. For other panels which are not wheeled L.38 and D.T.D.390 sheet are employed. The outside lapping edges of all skin panels are chamfered off. Riveting clamps of three types, General Aircraft, Myers and Spencer, are used for holding the skin temporarily in position. Where the skin has to be attached to the dural tubing, Chobert tubular rivets through only one side of the tubing are used.

To release the completed front fuselage, the wing-nut is screwed back and the retaining block is pulled away from the tube by an internal spiral spring. After the withdrawal of a pin the whole arm can be drawn back to clear the fuselage.

When the locating attachments have all been released and drawn back, the single support at the nose end of the jig is removed together with one or two other auxiliary supports. It is then possible to withdraw the completed fuselage nose first. Spray-painting, both internally and externally, is the next process, and this is done at an adjacent spray booth.

Fig. 197.—The jig for the Blenheim rear fuselage.

Installation of Equipment

The front fuselage contains the pilot's cockpit and to it from all parts of the machine are connected hydraulic pipe lines, electric wiring, flying, and armament and other controls. After being removed from the jig the front fuselage is placed on a wheeled stand and given over to the electricians and fitters for the installation of the necessary equipment.

Wiring has to be installed for all the lighting, including navigation, landing, formation-keeping and identification. In doing the wiring, the work is divided into four parts; starboard lighting, port lighting, ignition and bombing. The control column and pilot's seat are built as a separate sub-assembly and installed with its controls. Where wiring of controls will extend later into the rear fuselage, the correct length is cut off and rolled up in readiness. This is another example of doing a maximum of work at the earliest possible stage of construction, and avoids congestion during the final assembly, when there is room for only a small number of men to work on the structure. Everything possible is done at this early stage of manufacture; in addition to the equipment already mentioned, the automatic pilot controls and the fire control wiring are installed. Instruments are not put into the instrument board at this stage and,

in fact, are not installed until the aircraft has been flown to a Maintenance Unit of the Royal Air Force prior to its delivery to a squadron.

As there is no tail turret on the Blenheim it is not necessary to provide room for a member of the crew to pass through the rear fuselage, which is not, therefore, of large dimensions. In consequence the transverse **Z**-section rings are in one piece and are made from Alclad sheet. Production of the rear fuselage unit has been reduced to a simple process. A jig of the internal type is used with a skeleton of rolled steel angles. On these are mounted hinged locating points, five of which grip each frame securely. Stringers, pre-drilled for rivets, are threaded through the frame cutouts and the skin plating is then applied.

Plating the Rear Fuselage

As with the front fuselage, plates are clipped to the frames to stiffen them during the assembly operations. The familiar " bulldog clip " is used for this purpose and for holding skin panels in position before locating them firmly. It will be observed that that " Bowler hat " stringer is used with the top of the " hat " to the skin so that

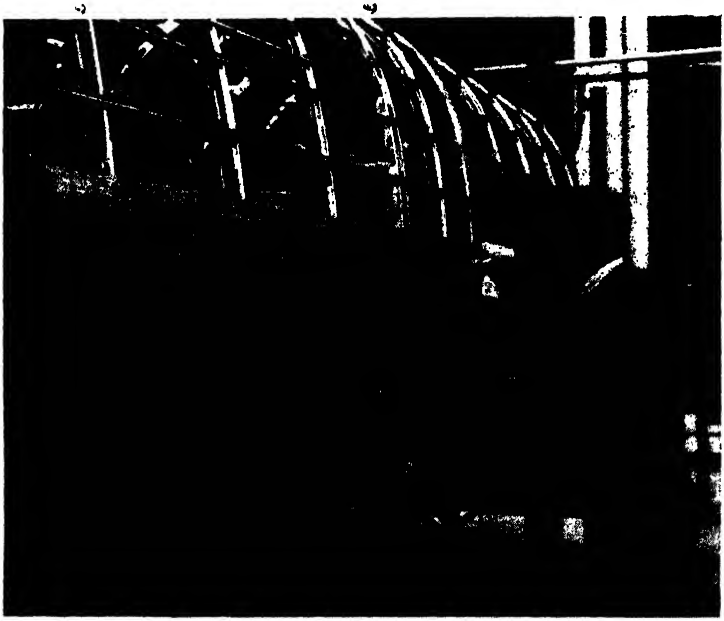


Fig. 198.—*Plating a rear fuselage.*

it remains an open section and is riveted by one row of rivets. Removal of the rear fuselage is an easy matter. The locating points are released and turned back and the shell removed tail first.

After removal it is spray-painted internally. As the fuselage is almost a closed chamber, the spray could be most dangerous to the operator who works inside it. For this reason a mask is fitted over the rear end. An exhaust fan sucks air out continuously during the spraying operation, which proceeds from rear to front. The exhaust is carried up to the roof and there discharged to the outside air.

Joining Front and Rear Fuselages

Although the front and rear fuselages are not joined until the main assembly, the actual nature of the joint will be considered here as it is of considerable interest. The joint is of the kind which might be called the " distributed stress " type, to distinguish it from the " concentrated load " joint, of which the Armstrong-Whitworth-Whitley fuselage attachment is a notable example. In the Whitley the front and rear fuselage

sections are attached by four pin joints. As the stresses in a monocoque fuselage are spread out over the whole skin, it is necessary to concentrate them into these joints. This requires members riveted to the skin, their function being to "pick up" the stresses.

On the Blenheim the joint functions by leaving the stresses in their "spread out" state and providing paths for them in the form of a large number of small screws which are used to make the joint along the whole length of intersection of the two surfaces.

The joint over the top of the fuselage is a simple joining up of the skin by a double lapping band secured by screws and Simmonds stock nuts. The centre plane intersects the fuselage near the middle and the shear stresses in the skin are transmitted to the front and rear spans and the upper wing surface by angle joints with closely spaced screws.

Bombs are stowed on each side of the keel, so that structurally the fuselage here has no lower surface but only bomb doors. The function of the keel is to transmit the tensile and compressive loads in the lower surface of the fuselage to the lower surface of the centre plane. Again the load is applied to the spar through a large number of screws.

The underside of the spar is connected to the fuselage, using a structural member which is detachable so that the spar may be removed by dropping it downwards.

This brief digression into the subject of loads and stresses will indicate how the adoption of this type of joint is affected by production considerations. Without some such attachment as the Simmonds elastic stop-nut its construction would not be really practicable, although it might be possible with considerable complication. Such a joint requires a nut which will lock the screw driven into it without the necessity for access to the far side. It is also essential that the nut shall continue to provide a securely locked joint even though the screw may be withdrawn and replaced many times during the life of the aircraft.

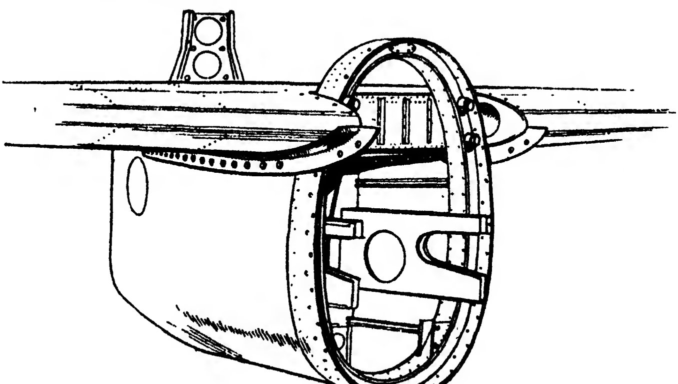


Fig. 199.—The tailplane is joined to the stern section of the fuselage by means of boundary angles and four large bolts through the front spar and the oval frame of the stern section.

Assembly of the Blenheim

All final assembly operations on the Blenheim are carried out in the erecting hall. The work is divided into three definite stages, known as "erecting hall, stage 1," "stage 2" and "stage 3." These are abbreviated to EH 1, EH 2, EH 3.

The first two stages are operational, while the third is concerned with inspection only. When the various main components such as fuselages, main planes and tail units have been completed, they pass to the main components reserve compound, where overhead cranes are provided for handling purposes. In EH 1 which is located next to the compound, are many main assembly fixtures, one for each machine. Alongside each of these is a stores crib complete will all details and parts required for EH 1 operations. The first of these is the attachment of the engine nacelles and undercarriage assemblies to the centre plane, which is then placed in a fixture by means of an overhead crane.

These cast-iron centre plane fixtures have been arranged so that they will lie in straight lines both along and across the factory and are set rigidly into the concrete floor. Though the original bedding-in was done with scrupulous accuracy and checked by means of an " iron horse " supplied by the Bristol Company, all fixtures are subjected to periodical checks on all dimensions. These checks are carried out by means of inside micrometers fitted with extension pieces about 20 feet long. Accuracy is held to very close limits; a deviation of 0.002 inch on such a length would pass, but an error of 0.005 inch would be considered excessive and an adjustment called for.

No staggering of fixtures is necessary for manœuvring aircraft as the overhead crane system makes it possible for finished work to be lifted out of its fixture and transported forward over occupied fixtures ahead of it. After the centre plane has been placed in the fixture, the front and rear fuselages are brought up and attached to it and to each other. It will be remembered that the joint is made by a large number of screws and Simmonds elastic stop-nuts. These allow the loads to remain as distributed stresses, in which form they exist in other parts of the stressed-skin structure.

Engine mountings and fireproof bulkheads are next fitted, and following these the fuel system, electric wiring, hydraulic system and flying controls are installed. The centre plane nosings are also offered up and positioned at this stage, but are afterwards taken off to be fitted finally in the EH 2 stage. The engines are mounted, also the exhaust rings and cowling gills. Fitting of the engines is made comparatively easy as they are transported into position by overhead cranes, the rails of which are arranged exactly over the centre lines of the engine mountings.

Another unit which comes to the EH 1 stage as a complete assembly is the tail unit, the stern frame having been constructed previously with tailplane, fin and tail wheel. As brought to the EH 1 stage, it is mounted on four screw jacks on a wheeled trolley so that it can be levelled exactly into position for bolting up to the rear fuselage; the fuselage joint is again of the " distributed stress " type.

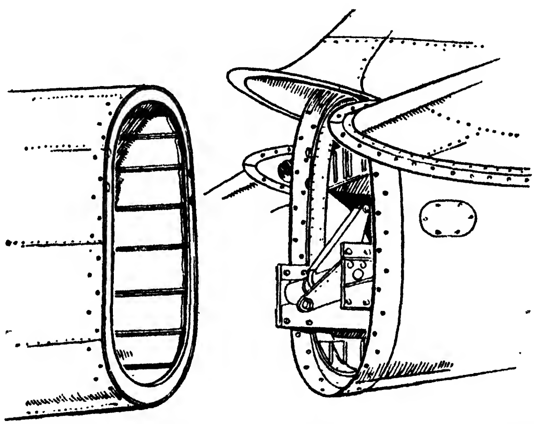


FIG. 200.—*Structural details of the joint between the tail unit and rear fuselage.*

Completion of EH1 Stage

After the attachment of the tail unit has been completed, the rudder and elevator are assembled on their hinges and the controls for these surfaces are then connected up. Alignment is carefully checked by means of plumb bobs and the measurement of diagonals. Controls are tried and checked and the partly-assembled aircraft is then ready to be removed from the fixture. This is accomplished by the overhead tandem cranes which lift it bodily upward. From the forward 3-ton hoist is dropped a gallows fitting which takes the weight at the engine nacelles, while the 1-ton crane lifts the rear end by means of a wide webbing strap encircling the fuselage. The foreman then operates the controls for the conveyance of the machine forward to its position in the EH 2 stage.

Inspection both by the firm and A.I.D. is carried on simultaneously with the assembly processes. It is in the EH 1 stage that contact is made with the M.A.P. Supplies Department, which issues to the works all the armament equipment, airscrews, engines

and other parts which are not produced at the Rootes factory. Electrical sub-assembly work has a shop to itself, and here are made up instrument board assemblies, bomb gear panels, wireless crates and similar units.

In the EH 1 stage the machine is carried on two cast-iron fixtures in which it is located by means of locating pins through the spar fittings of the centre plane. In the EH 2 stage, however, it rests on the floor on its undercarriage, which is lowered and locked in position while the machine is suspended from the cranes.

The rear fuselage is still supported on a movable trestle so that the aircraft is in flying or rigging attitude. Working platforms are provided between the engine nacelles and the fuselage.

The EH 2 stage consists of four sub-stages. Main planes, complete with flaps and ailerons, are brought along by overhead cranes. The EH 2 area of the erecting hall is well provided with such cranes of 1-ton capacity, operating on the mono-rail system. The main planes are lowered into their correct positions relative to the centre plane, and rest temporarily on longitudinal adjustable trestles until the wing joints are permanently bolted up.

The wing flying controls are first connected up and inspected, and the rotating gun turret and the complete hydraulic system installed. This completes the first sub-stage, and after the wing trestles have been taken away the machine is moved forward. The tail trestle is not detached, but is also moved forward, being mounted temporarily on a portable truck.

Fig. 201.—A rotary shear is used for cutting the blanks for the fuselage frames, which are made from single sheets of Alclad.

Progress on the Assembly Line

In the second sub-stage, the hydraulic system is connected up to a portable testing plant. All hydraulically-operated units, such as the undercarriage, turret and flaps, are then thoroughly tested. After this the machine is moved forward to the third sub-stage of EH 2 assembly. This is concerned with the completion of electrical installation and the testing of all such work over the entire machine. Windows are fitted and all auxiliary services are installed.

Another move forward takes the aircraft into the fourth sub-stage, in which the engine cowlings are attached, all foreign matter removed from the interior of the aircraft structure by portable suction plant, and all lubricating points thoroughly greased.

EH 3 is the only remaining stage of final assembly and consists entirely of inspection. A staff of inspectors examines the aircraft throughout; the inspectors are followed

by mechanics who make any necessary rectifications. This inspection is performed both by the firm and the A.I.D., and when the aircraft has been passed it is wheeled out through the large doors at the end of the factory building on to the tarmac. Only two processes remain to be carried out. These are the application of the external finish and the final adjustments for flight, which are made in the flight shed. The aircraft is then ready to be flown away.

If the adjustment work on it is of more than minor importance and is likely to hold up the steady forward movement of other machines behind it on the assembly line, a rectification bay is available into which any machine can be sidetracked until released by the inspectors.

The Dope Shop

The paint and dope shop occupies a building specially designed for the purpose and separate from the main factory. Special plant is provided for air-conditioning and temperature control. Heating apparatus is installed in the roof, where outside air is drawn in, passed over radiators and blown down through louvres. As the air becomes charged with surplus dope from the spray guns it is drawn out by exhaust fans through exit ducts in the floor. In this way the air is kept as pure as possible for the operatives. Beneath the floor is a series of channels in which the electric motors for driving the fans are housed. These channels provide access to the motors for maintenance purposes, and servicing therefore does not interfere with spraying operations in the shop.

All the dopes and finishes except the undercoating, which is applied first to fabric, are put on by spray gun. The mixing plant, supplied by Aerograph, Ltd., is housed in a room adjoining the dope shop and consists of ten mixing vats, each of 55 gallon capacity. To ensure uniformity throughout, the contents of each vat are kept continuously mixed by an electric pumping plant. This plant also makes available the various dopes at all the spray booths throughout the factory through a system of copper lines, five miles of which have been laid. For any spraying operation it is merely necessary to connect up the rubber hose of the spray gun to the pipe line supplying the dope of the required colour.

An unlimited supply of dope of the correct viscosity is at once available under pressure at any point in the factory. The work of the dope shop is confined to certain stages of assembly. Main planes are sprayed after they have been plated and the complete aircraft is also treated after it leaves the erecting hall. All other spraying of small parts and sub-assemblies is performed at spray booths situated at convenient points.

The only parts of the Blenheim not metal-covered are the three control surfaces, rudder, elevator and ailerons. These are covered with fabric in a section of the dope shop where the undercoating of dope is applied by brush to work it into the material.

External Finish

Aerodynamic research, both theoretical and experimental, has shown the great importance of surface finish on fast aircraft. In the treatment applied in the dope shop every attempt is made to make use of the knowledge so gained. When the machine is brought into the shop it is first " masked " with paper over parts which must not receive the dope, such as windows. It is then cleaned up and given one primer coat all over. The next process is to stop all small holes, such as hollow rivets, and to tape all lines of projecting rivet heads on wing or other surfaces with strips of madapolam. This is done to reduce aerodynamic drag. Next comes a flatting-down process, followed by the application of a filler coat and a levelling coat. All this is done to produce a smooth external surface. Two coats of brown and green camouflage are then applied and finally a coat of thinners. Underneath, camouflage is not applied, a pale " camoutint " being employed instead.

After doping and finishing have been completed the aircraft is wheeled to the flight shed, where final adjustments are made.

Oil and fuel tanks are filled from sunken reservoirs under the tarmac. The machine is then set up in flying attitude on trestles for various adjustments and checks. These include alignment of the guns, carried out on a sighting board, set out in front, tests on the rate of petrol flow along the pipe lines, a check on the pressures in the undercarriage legs, fitting and adjustment of airscrews, fitting of sparking plugs, and cleaning of the windscreen.

When this work has been passed by inspection, the engines are run and the engine instruments are checked. A rotoscope is used to determine r.p.m. by observations

on the rotating airscrew and the revolution-counter reading on the instrument board is checked against it.

A manometer is used to find the boost pressure as a check against the boost gauge. After such a run the two engines are given a general check-over and all filters are removed and cleaned. When the company's inspection staff is satisfied, the aircraft is handed over to the A.I.D., who then make independent tests, finally giving it a "certificate of safety for flight."

Flight Shed Equipment

Equipment in the flight shed includes a 2½-ton overhead crane for general work, a 4-ton weighbridge in the floor and a 4-cwt. spring balance suspended from the roof, for determination of centre of gravity. There are also an accumulator charging plant, a 10 foot surface table for checking the blade angles of airscrews, a portable hand crane

Fig. 202.—The pilot's seat and control unit are built as a complete sub-assembly.

and a 28 h.p. tractor. This last is equipped with 600 feet of wire rope for pulling aircraft in when the aerodrome is boggy.

After completion of flight-shed inspection, the chief test pilot takes over and submits each aircraft which goes through his hands to a series of flying tests. It is then returned to the flight shed apron and the compass swung on the base. Nothing remains now but to make any small adjustments called for by flight tests and to prepare the machine for being flown away.

When ready, aircraft are taken over by ferry pilots of Air Transport Auxiliary, who fly them to a Royal Air Force Maintenance Unit. Here, some of the operational gear, such as radio, oxygen and ammunition is installed, and the completed Blenheim is then flown to the squadron with which it will serve.

Beaufighter Construction

TURNING from Blenheim to Beaufighter, it is interesting and perhaps may be significant that the Bristol Aeroplane Co., after using in Blenheim the " distributed stress " type of joint made with a multiplicity of small nuts and bolts (see page 264), should change in Beaufighter to the " concentrated load " type of construction, making use of pin joints.

Structural Features

The main features of Beaufighter fuselage construction do not depart from what has now become orthodox semi-monocoque design in aluminium alloy except in so far as the structure has two keels running the length of the fuselage. Otherwise, this unit has the usual transverse frames and longitudinal stringers intersecting them at cutouts. The frames are of Z-section, except at points of heavy loading, where they are box-type. Stringers are bulb angle extrusions, or an equivalent rolled section can be used as an alternative. Heavy longitudinal members or longerons take the place of stringers on the edge of the observer's post at the rear and at points of concentrated loading such as the pin joints between fuselage and centre plane.

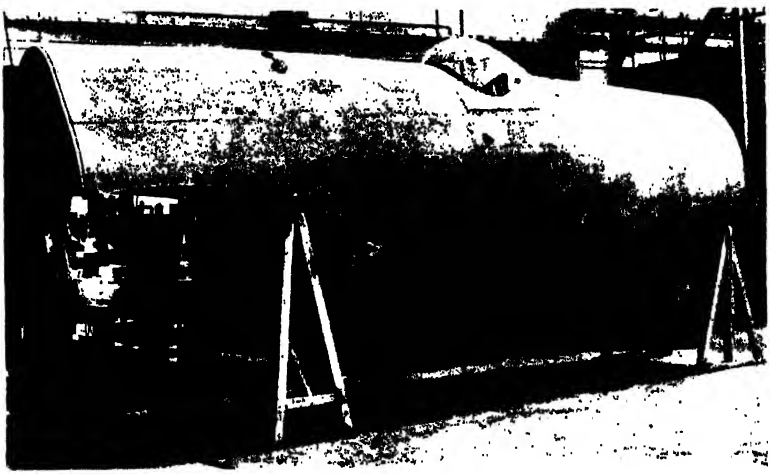


Fig. 203.—Rear fuselages as delivered to the factory are completely assembled.

All external riveting throughout the whole aeroplane is flush and the smoothness of the plating is as high as has ever been seen on any other machine. The joggling of each panel of skin along all four of its edges to make all joints flush has increased and complicated shopwork, but this is part of the price which must be paid for the increased smoothness demanded by the modern design office. The aluminium alloy sheet on the Beaufighter is of the Alclad type and conforms to Specifications D.T.D.390 and L.38.

The wing is an orthodox two-spar structure with skin of flat aluminium alloy on upper and lower surfaces. Spar construction is unusual and makes use of sections only recently available due to advances in extrusion practice. The web is of flat sheet and the booms are heavy extrusions of nearly rectangular section (approximately 3 inches by 1 inch) with a lip on one side to facilitate riveting to the web. The material is aluminium alloy L.40. This section has the advantage of being easily machined on the side without the lip if for strength reasons it must be tapered.

With the small exceptions of the fabric covering on the control surfaces and the wooden edge of the wing tip and tailplane tip, the whole of the Beaufighter is of metal construction. The wing and tailplane tips are of multi-plywood formed to shape during gluing. Two large panels on the underside of the centre plane are detachable

for fuel tank installation and removal and are attached by closely spaced stop-nuts. Under each outer main plane there is also a similarly removable panel for access to the control cables and wiring.

Cable-type controls are used throughout the machine except for the trimming tabs and landing flaps, which have M.R.C. controls. The ends of cables are attached by the latest method of swaging them on to the wire cables. This process gives a very neat and structurally efficient joint.

Assembly Operations

The first assembly operation is the attachment of the two-spar tailplane to the stern section of the fuselage by means of the four pin-joints. Next the fin is similarly

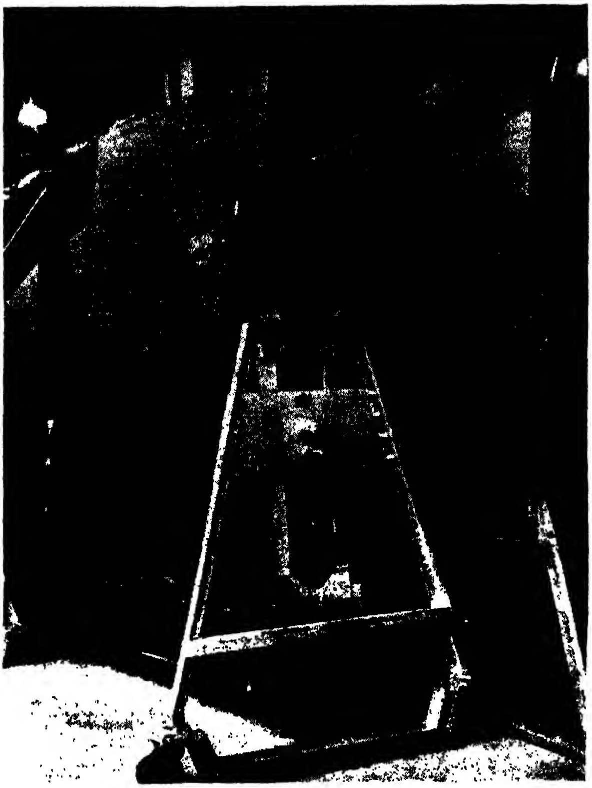


Fig. 204.—A welded steel fixture for storage of the centre plane.

bolted on. Simultaneously, installation work proceeds on the fore end, girl labour being largely employed for the purpose. Even the complicated work of installing electric wiring is handled by girls,.

Although the cockpit is small, it has much equipment. This is to be expected in a twin-engined fighter which has four shell guns and six machine guns and operates with radio-location.

Assembly of the aeroplane is based upon the centre plane around which all the other components are built. This unit is set up between two cast-iron fixtures by means of pins through the four wing spar joints at each end. The first set of pins have the knurled ends painted green to indicate that they are to fit the unreamed holes. Another set at each fixture, painted red, is for use after the holes are reamed.

The section carrying the pin joints is not a continuous part of the fixture, but is attached to the main body by three bolts. When the aeroplane is lifted from the fixture these three bolts are released, not the pin joints. When it is clear of the fixture the pins are removed and the pieces of the fixture detached and restored to their positions. This procedure is necessitated by the fact that the spars of the wing have an inclination of 3° to the vertical when the structure is in the fixture, which would consequently be fouled by a vertical lift if only the pins were removed.

When it arrives at the fixture the centre plane is almost complete. All the upper surface and some of the lower surface skin has been attached and all flying controls and electric wiring have been installed. When it has been set up, the rear fuselage is brought to the assembly and offered to the centre plane on a wheeled steel trolley specially designed for the purpose. The four screws enable the rear fuselage to be adjusted for height and level so that its pin joints can be matched up exactly with those of the centre plane. The stern section is then added, this also being offered up on its steel trolley. This joint is the only " distributed stress " type in the structure, being made with small nuts and bolts closely spaced round the whole perimeter. The skin of the stern section overlaps that of the rear fuselage, which is not pre-drilled.

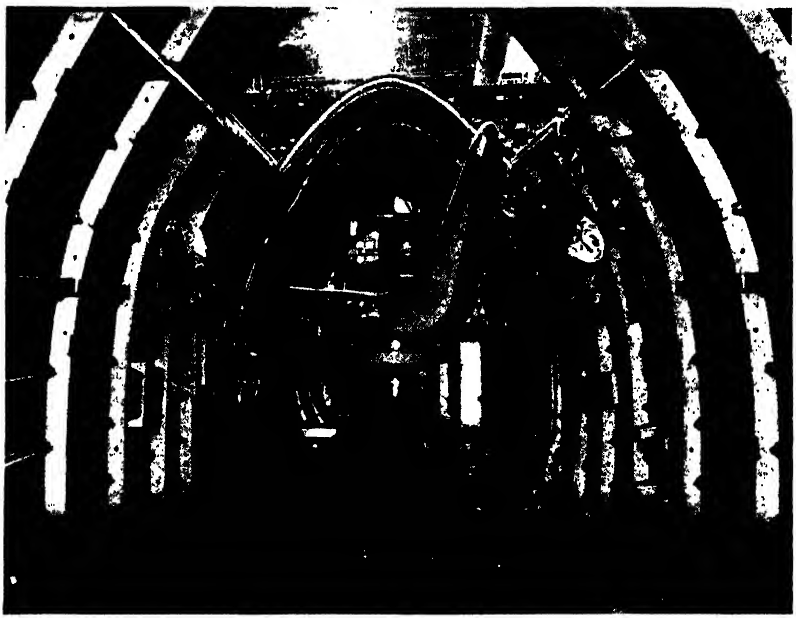


Fig. 205.—Interior of the Beaufighter fuselage, showing the Z-section and box frames, the bulb-angle stringers and the floor built on two longitudinal keels.

This allows the stern section to be set up accurately with the fin vertical. Drilling is then completed and the joint finally bolted up. It is also in this stage of assembly that the parachute escape hatches, two doors in the underside of the fuselage, are fitted.

Simultaneously the fore end is offered up and pinned finally into position; work then proceeds on the attachment of the undercarriage and the retractable tailwheel. Both of these, like all other components, are received in the assembled condition. The undercarriage is a structure of square tubes bolted together, and each unit arrives complete with oleo legs and wheel. Attachment of the engine nacelle follows.

Engine Installation

Installation of the engine is the next operation, and is accomplished by means of a portable electric crane of one-ton capacity. To facilitate the assembly, two white lines are painted on the floor. If the wheels of the crane track along these lines the engine will be in the correct position for lowering on to its mounting. This is a small point, but one which in total can save many vital man-hours.

Other work which is completed in this stage of assembly is the fitting of rudder and elevator and the completion of flying controls. Engine controls are also fitted as far as possible at this stage. The assembly is then removed from the jig by means of two portable cranes, which lift from the lower surface of the mainplane between the engine nacelle and the fuselage. The cable of each crane passes through a hole provided in the top surface of the wing by the omission of a panel of skin and is attached to a temporary member which bears on the underside of the two wing spars. After being hoisted out of the jig, the assembly is lowered on to its own main wheels, but its tail remains in flying attitude supported on a trolley.

Main Plane Assembly

Offering up the outboard main planes is the next stage. The degree of completeness of these wing sections is another tribute to the excellence of the dispersal organisation which allows the many components to be constructed at widely separated factories. Flaps and ailerons are already fitted, as well as all the electric equipment and flying controls. Four machine guns are installed in the starboard wing and two in the port wing, this unequal division being necessitated by the presence of the landing light in the port wing. Gun mountings, cartridge chutes and the engine oil coolers are all in place when the wing is received.

The mechanism for the flaps and ailerons is then connected to that part of it which has already been installed in the fuselage. Machine-gun installation in the main plane is completed and the pitot head attached to the underside. Fuel and oil tanks are also mounted and the pneumatic system for the operation of the brakes and the wing guns is installed.

Next follows the fitting of landing lights and the cabin heating system. Engine controls are also completed as are all the cockpit controls, including those for the fuel, oil, and hydraulic systems. Much of this work is done round the fore end of the fuselage and on the engines, and convenient travelling platforms are moved into position for the purpose. Though mounted on casters for easy movement the platforms have screw-down feet for fixing them in position.

In the next stage is carried out the attachment of the cockpit hood and windscreen, the undercarriage doors and the doors covering the shell-gun compartments. Work on the electrical system is completed and the fuel-jettison system installed. The outlet pipes, of 4 inch diameter, discharge at the rear of the undercarriage doors. Vickers jettison valves, air-controlled, are fitted. The doors for the shell-gun compartments are of a novel design which appears to be easy to produce. They are of all-wood construction and have been manufactured from sheets of thin plywood bent to shape and stiffened by wooden members round the periphery. Curved wooden members glued in position over the whole surface preserve the contour and prevent any deformation. This form of construction is sufficiently rigid to give dimensional accuracy of such an order that the doors are interchangeable even though made of wood.

Testing of the various electric and hydraulic systems and all the controls is the last stage of assembly. A portable hydraulic tester is used for putting the undercarriage through an operation test. During this test the pressure gauge registers pressures varying between 750 and 1,000 lbs. per sq. inch, but the undercarriage system can work up to 1,200 lbs. per sq. inch.

Painting is the final operation, and being a night fighter, the Beaufighter is finished in the dullest black imaginable. This finish has a slight matt surface to eliminate any chance of reflection, and has been given the suitable designation of "night." It is quite remarkably black.

GEODETIC CONSTRUCTION

THE VICKERS-ARMSTRONG WELLINGTON

BY C. M. POULSEN

DUE to the relatively high density of the structural materials used (Duralumin, Alclad, etc.), and to the comparatively low loads encountered, a metal skin must be used in very thin gauges if the weight is to be kept within reasonable limits. That means that the strength of the skin in compression is fairly low, and failure occurs through secondary buckling of the skin. In order to enable the thin metal skin to carry loads more commensurate with its actual strength, it is usual to reinforce it with transverse rings or hoops and with longitudinal stringers. These split the surface into a number of small panels in which the ratio of length of sides to the gauge of material is reduced and the skin is enabled to develop a greater percentage of its strength before buckling occurs.

The ideal would, of course, be a material of sufficiently low density to enable it to be used in much thicker gauges, so that it would be stable without the reinforcement of stringers and rings. The result would then be a sort of " lobster claw " construction

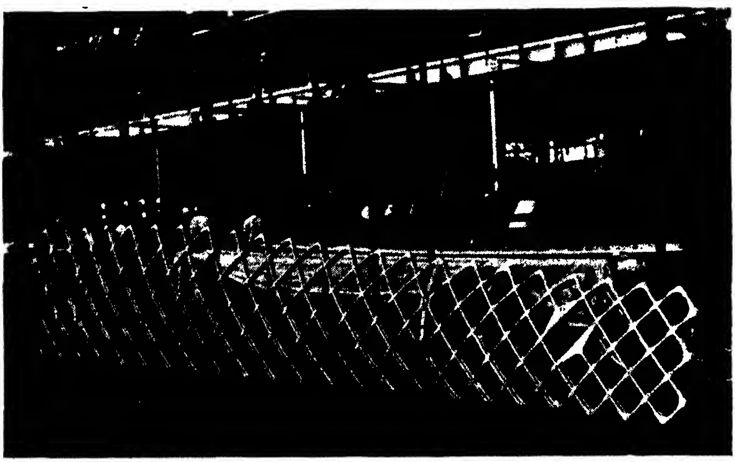


Fig. 206.—Fuselage side panel made up as a unit.

entirely free of internal members and without rivets. No such material is yet available, and for the present it is necessary to make do with those we have. We then have the alternative of either " spreading them out thin," as in the stressed-skin type of construction, or of concentrating them in channels or tubes or other sections, suitably located to take the loads, using a fabric covering to give the external form.

All who have an opportunity of observing stressed-skin aircraft at close quarters will have noticed that the stress wrinkles always run diagonally from corner to corner of panels. This fact indicates the direction of maximum loads in the skin, and in the geodetic type of aircraft construction introduced by Mr. B. N. Wallis, the members will be observed to run diagonally, just as do the stress wrinkles in a stressed-skin structure. In other words, the members have been placed just where the maximum loads occur, and are thus used in the most economical way, judged from a strength/weight point of view.

The geodesics are channel sections made from strip, and the forming of the section presented no difficulties. Experience of strip construction goes back many years, to the days of all-metal construction in steel, and the technique of forming is thus very developed. In geodetic construction, however, an extra complication is introduced by the fact that the geodesics are curved. Moreover, their curvature does not form

an arc of a circle, owing to the fact that they have to lie in the surfaces of a streamlined fuselage and bi-convex wing sections. In some places the geodesics are nearly straight for a portion of their length and then suddenly have to be bent to a curvature of fairly short radius.

These considerations led to the development of a special machine which forms the channel section and bends the member in the plane of the channel at the same time. If all the geodesics had been alike, this would have been a comparatively simple operation, but they differ in length and curvature all along the wing and, more particularly, throughout the length of the fuselage.

Rolling the Channel Sections

Fundamentally the machine tool is an ordinary rolling mill, with several pairs of rollers which gradually form the flat strip into the desired " hollow-back " channel section. It is in the arrangement for bending the channels that the special features are introduced. Top and bottom rollers of each pair are driven by shafting from the back of the machine. Universal joints are incorporated in the shafts in order that swivelling of the roller cages, demanded by the curvature of the channels, may be accommodated.

It will be understood that the forming of the channel section has been practically completed before the bending operation begins. As the curvature has to be put on gradually, the rollers in their cages are traversed progressively, the first pair of the movable ones moving but very slightly, the next a little more, and the last a great deal if the particular geodesic is of deep curvature.

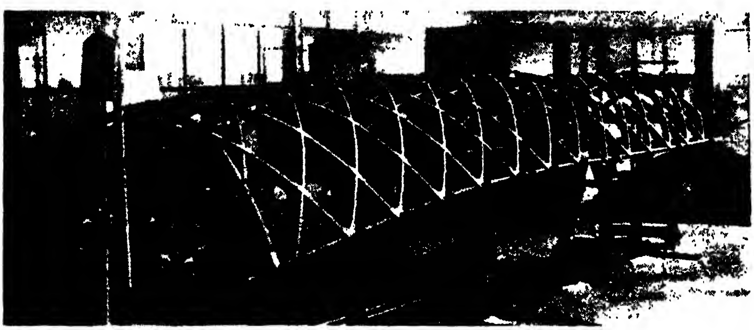


Fig. 207.—The assembly jig used for the top decking of the fuselage.

When the bend in the channel is pronounced, as it is in many of those used in the fuselage, the distance moved and the swivelling of the roller cage would be more than could conveniently be taken care of by a shaft drive, even with universal joints. For the drive of the last pair of rollers, therefore, an electrical drive is provided. The traverse, as before, is done mechanically by a rack and pinion gear.

Bending the Geodesics

The chief feature of this special rolling mill (which is fully covered by patents) is the method of traversing the roller cages progressively for forming the bend in the geodesics. The lateral movement of the roller cages is governed by cams. Three pairs of rollers are subject to traverse, the last, as already mentioned, having its rollers electrically driven. There are therefore three cams, or rather stacks of cams, for each stack is composed of thirty-two individual cams. The diameter of the cams is graded, those of the stack which forms the beginning of the bend being the smallest and those of the last stack the largest.

Movement of the roller cages is transmitted from the cams via a series of small rollers carried in a vertical " comb." This is in turn attached to a yoke connected to the slides that carry the roller cages. Each of the small rollers in the " comb " is located by a distance piece, the lengths of these distance pieces being so chosen as to give

Fig. 208.—The rolling mill at work.

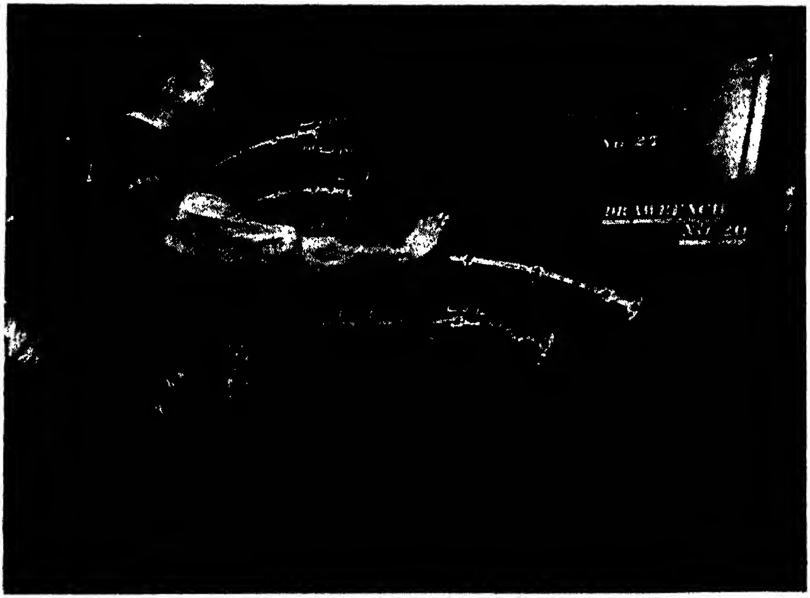


Fig. 209.—Testing geodesics for curvature in a gauge after they have left the rolling mill.

the amount of traverse, or in other words the degree of bending desired to the geodesics. The longer the distance pieces the greater the amount of bend. By using distance pieces of different lengths, the same cams serve for all degrees of bend.

The small rollers in the "comb" form a symmetrical curve, or strictly speaking a series of small steps arranged in a symmetrical curve. Only one half of each curve determines the bend; the other half is used for balancing the side load on the cam spindles. The small rollers are kept in contact with the cams by pneumatic pressure operating the yoke which carries the "comb." Thus when the cams have reached their maximum position, the yoke and rollers are returned by the compressed air.

It will be obvious that channels of different curvatures require different speeds. This is effected by interchangeable gears between the motor and the rollers which form the channels. The speed of traverse varies, of course, in proportion.

Reference has already been made to the fact that the geodesics are of different length as well as of different curvature. The latter is determined by the lengths of the distance pieces in the "comb," a different set of distance pieces being used for different curvatures. The length is not in such need of accurate treatment, as each channel is in any case cut to exact length at a later stage. For the first rough cutting off it suffices to part the channel with a hacksaw. This is done without stopping the

Fig. 210.—Assembling the geodesics into panels. Note: the notching of the crossover points.

machine, a dial indicating to the operator at which moment to begin sawing. It would obviously be possible to make even this operation automatic, but this has not been thought necessary, and parting by hand has the merit of great simplicity.

The channels leave the rolling mill bent and roughly cut to length. They are then taken to a steel plate gauge on which their curvature is checked. Any which require too much springing-in are taken to a small hand-operated two-roller tool in which the forming is finished off. Any slight bending or straightening which may be required is dealt with by placing one end of the channel between two steel jaws and bending or straightening by pulling on the other end.

That any hand working on the channels should be necessary after they leave the rolling mill is due to the fact that the material is never entirely homogeneous. One batch of strip will be just a little harder or a little softer than the previous one. This

affects "spring-back," etc., very slightly, but sufficient sometimes to require the finishing by hand to which reference has been made. Mostly this work is needed to remove any twist of the channels, shown by their refusal to lie flat on the steel plate gauges on which each one is tested individually after leaving the rolling mill.

Assembly of Geodesics

With geodetic construction, manufacture is essentially a question of forming the geodesics, cutting to length, drilling and punching holes, and notching at the cross-over points. After that the assembly is largely reduced to the simple process of placing the geodesics in jigs and riveting them together to form panels of larger or smaller size, according to the particular unit that is being made. Forming and shaping in place on the job is reduced to a minimum.

After leaving the rolling mills the geodesics are passed, by truck or conveyor, to a gallery above the rolling mills. Here they are loaded into jigs mounted on tables and the necessary holes are drilled in flanges and webs. Each of these jigs consists of a series of locating blocks fitted with drill bushes. The blocks are mounted on a steel plate and set to the curvature of the geodesics. The clamps which hold down the geodesics are also hinged to these blocks.

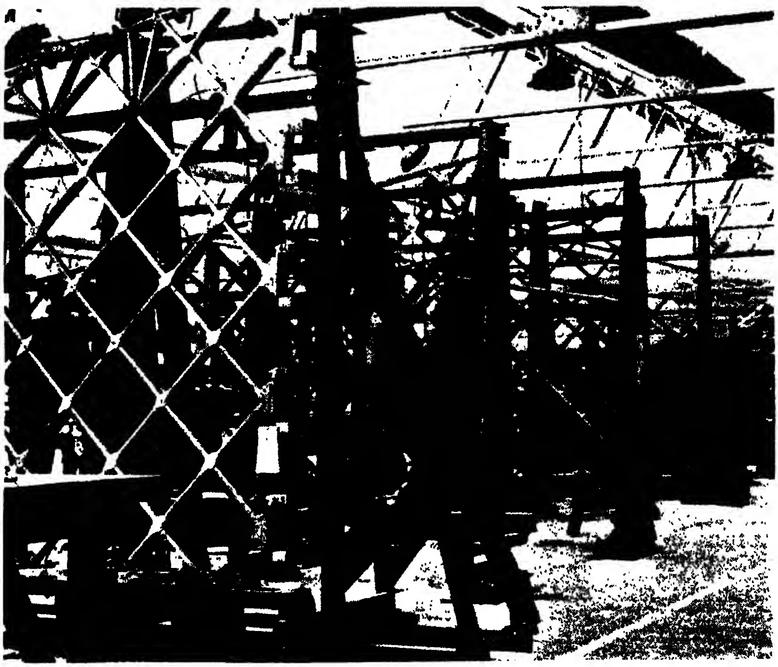


Fig. 211.—Wing panels on assembly jigs.

Another operation performed while the geodesics are in these jigs is forming the slight dent needed to bring the "butterfly" connecting members into the centre of the channels. These fittings are used for bolting together the geodesics at cross-over points. They are shaped like a wing nut, but are not tapped, and one is riveted to the geodesic channel at each point where a cross-over occurs, adjacent to the notch or cut-out which receives the other geodesic. It might be mentioned as a matter of interest that these butterflies are made from extruded sections. The operation of forming the dent for the butterfly is carried out by means of a square punch inserted through a hole in the steel plate clamps of the drilling jigs, the punch being hit smartly

with a mallet. Notching, or cropping, is the next operation. This is done on small hydraulic presses, the geodesics being located by pegs engaging the rivet and bolt holes made in them during the previous operation.

The geodesics are cut roughly to length by a hacksaw as they pass through the rolling mill. Cutting to exact length, and rounding the ends of the channel flanges, is done on small hydraulic presses, in a manner very similar to that employed in cropping. The geodesics then pass to the adjacent frazing department, where girl workers smooth the rough edges of the channels with files.

Attaching the Butterflies

Before being sent to stores, ready for issue to the assembly shops, the geodesics have the butterflies riveted on. This is done, also by girl workers, on small hydraulic riveters. The ends of the butterfly body are next pinfaced on small drilling machines. A peg on the table and one on the small pinfacing cutter used in the drill prevents the cut from being taken too deep and ensures exact length of the bodies of the butterflies.

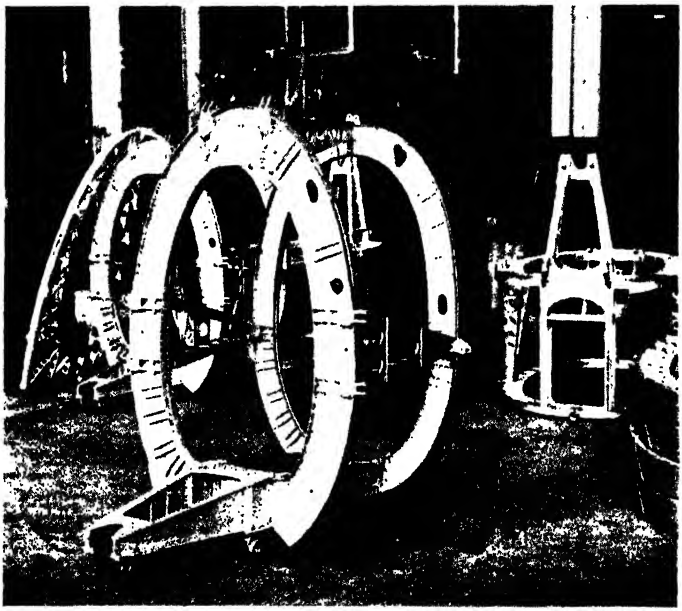


Fig. 212.—Tailplane and tailwheel are carried on a separately assembled double-frame unit.

These operation finish the geodesics, which are sent to stores after the usual inspection. In view of the many different lengths and curvatures used, an elaborate system of numbering has been evolved, so that when a girl worker is ready to begin on a new panel, she is issued with the requisite number of geodesics of the appropriate length and curvature.

Theoretically, if every geodesic were of exact length and curvature, and if all bolt and rivet holes were exactly located, it should be possible to assemble them into panels without the use of jigs. Such accuracy is, however, scarcely to be attained, and assembly jigs are used for the wings and fuselage panels.

The principle is similar in both cases, except for the fuselage top and bottom, which have the tubular longerons riveted to them. A wing panel will, therefore, serve as an example of the general system. As already mentioned, the panels are assembled by girl workers, each is issued with the exact number of geodesics for the particular

panel she is assembling. The jigs are built up of structural steel girders of channel and angle section. The two ends of each geodesic are held in lugs on the jig, and when all have been placed in position, the operator secures them together at the cross-over points by single bolts through the gusset plates and "butterfly" bodies.

In order to avoid confusion, the gusset plates are painted different colours, outside plates yellow, inside plates green. The fishplates are riveted to the flanges of the geodesics by pneumatic hand riveters. The plates at the ends of the geodesics, that is, at the edges of the basketwork panels, are also riveted on in these jigs, from which the panels are removed as complete units. They are transferred from the jigs to adjacent bins in the wing gallery, where they await transport to the larger erecting jigs in which the panels and other members are assembled into bigger units or complete components.

The fuselage side panels are assembled in exactly the same way, but, as previously mentioned, a slightly different procedure is adopted for the top and bottom units of the fuselage. This is necessitated by the fact that not only have these sections a much greater curvature, but they have the top and bottom longerons attached to them.

For the fuselage decking a very substantial jig is used, with uprights of channel section structural steel. The tubular longerons are held securely in the jigs. These

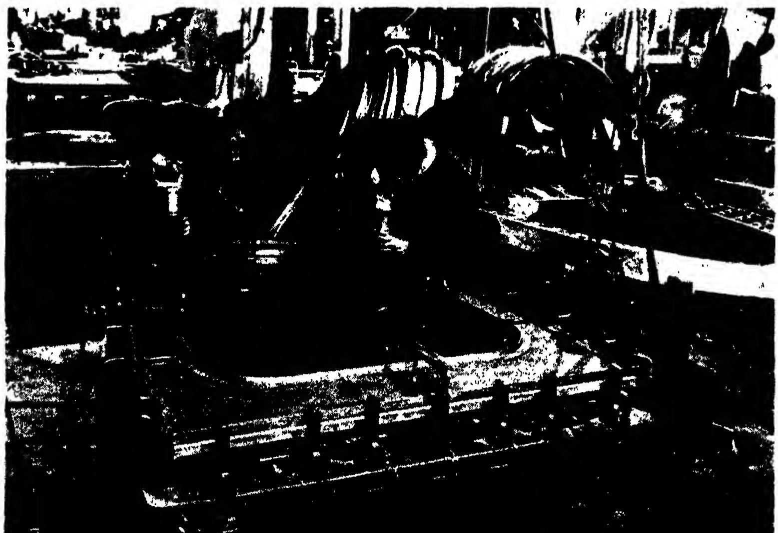


Fig. 213.—Flanges and stiffeners are riveted to the main frame webs in a special assembly fixture.

members have considerable bends in them, owing to the way in which the relatively flat sides intersect the deeply cambered top, and to the slight "waisting" of the fuselage towards the stern. They have previously been drilled in another jig, so that when the top decking is being assembled, they serve to locate the ends of the geodesics. The cross-over points are bolted together and attached to the channel flanges by gusset plates, exactly as in the case of the wing panels already described.

Main Fuselage Frames

The main fuselage frames form the whole basis of the fuselage erection and everything is trued up in relation to them. Three or four types of fuselage frame are used, but here we are concerned only with the two which support the front and rear auxiliary

spars of the wing. It should be explained that the main wing spar, situated at approximately one-third of the chord from the leading edge, is not attached to the fuselage at all, but "floats" in openings in the fuselage sides. The front and rear spars, or more correctly speaking the leading and trailing edge spars, are bolted by cardan joints to the two main fuselage frames. These are built up of a heavy-gauge flat central web, with riveted inner and outer flanges and channel-section stiffeners. The two frames are almost identical, except for very minor variations, and of course the lugs to which the spar roots are attached are placed higher on the leading edge frame than on the trailing edge frame in order to give the angle of incidence to the wing.

These spar frames are built up on flat horizontal table jigs, one of which is a drilling jig, while the other is an assembly jig in which the flanges and stiffeners are riveted to the flat web or bulkhead.

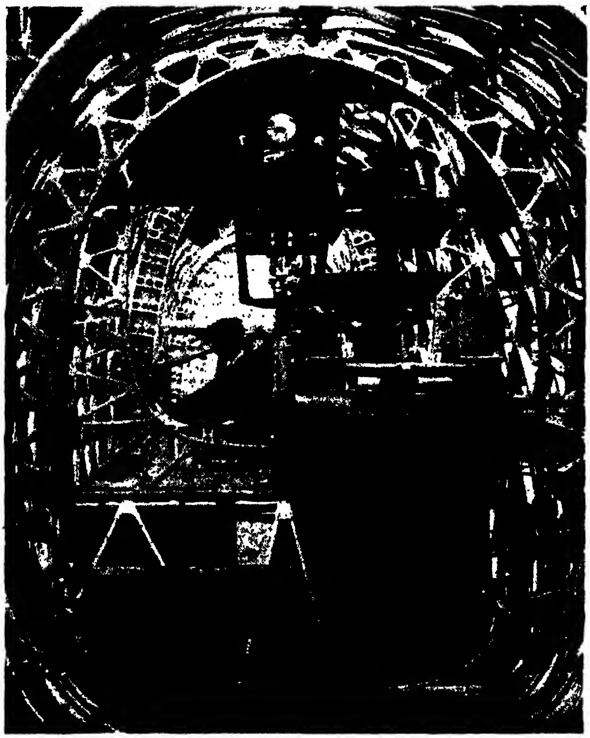


Fig. 214.—An intermediate stage of equipment installation, showing the control column, rudder bar and framework of the pilot's seat in position.

In the main fuselage erecting jigs, which are built in pairs, the top decking is first suspended temporarily from the upper cross-members of the jig while the frames are placed in position. The two wing spar frames are located in the jigs by the lugs which later are to receive the spar roots. The top decking is then lowered on to the frames and riveted to them, and the side panels are attached. The fact that the ends of the geodesics in top and bottom decking are staggered in relation to those of the side panels makes for simple attachments and ready access during the erecting operation.

When assembled, the side panels and top decking make a complete structure, so that the whole fuselage can be withdrawn from the jig and placed on trestles elsewhere in the shops, where the work of installing equipment is carried out.

This is greatly facilitated by the open geodetic construction, which gives ready access to every part of the interior and enables men to work from the outside as well as the inside for many of the operations. The fabric is not attached until practically all the equipment has been installed. In this respect the production of the fuselage differs from that of the wings, in which the geodetic panels are covered with fabric before being taken to the wing assembly shops. On the fuselage the fabric is carried on wooden stringers, which are laced with cord to the geodesics. This is made possible because the loads encountered are much smaller than those to which the wing fabric is subjected.

In the Wellington wings there are three spars throughout, of which one runs right through the fuselage without being attached to it. The other two are auxiliary spars, one situated at the leading edge and the other at the point of the trailing edge where the flaps and ailerons are attached. The three spars pass through the engine nacelles, joints being provided where they emerge from the nacelle covering on the outboard or wing tip side.

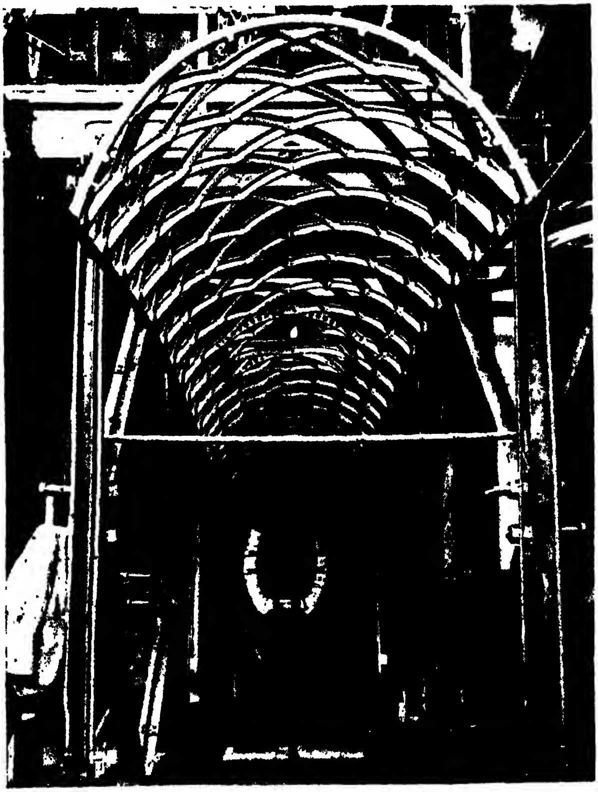


Fig. 215.—The top decking of the fuselage, complete with longerons, ready to be dropped on to the main frames.

Front and rear spars have tubular booms and flat sheet webs, but the centre spar is much more substantial and of different construction. The spar booms are solid-drawn tubes, and the web is of girder type, with bracing members of channel section. The tubes are lightened by having the outside diameter turned down between the points where bracing members are attached. Special machines have been introduced which, with multi-tool saddles, have greatly speeded-up the operation.

Fig. 216.—The de Bergue riveting system is employed in the Wellington fuel tanks.

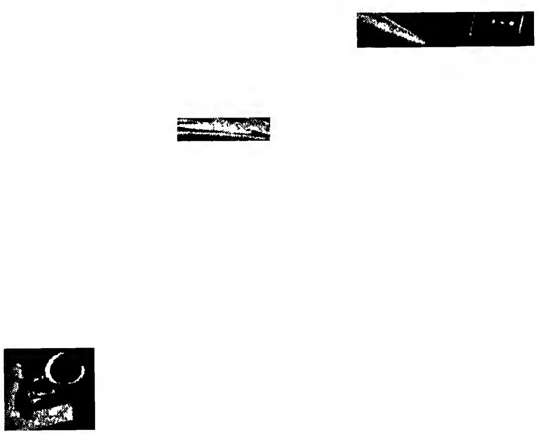


Fig. 217.—A complete wing tank. It will be seen that it is built in three interconnected units.

As the main wing spar is the basic member from which the wing is trued-up, it is essential that the spar tubes should be accurately aligned and perfectly straight. To ensure that this is the case, use is made of a Taylor-Hobson alignment telescope, in which a collimator is placed at one end of the tubes and the special telescope at the other.

The bracing members, as already mentioned, are of channel section, and are formed in the rolling mill in the ordinary way. After being cut to length, they are placed in their proper formation, Warren girder fashion, in the drilling jig, which has two tubes to represent the spar booms. In this jig the bracing members are drilled and the end plates riveted on. The end plates stiffen the members sufficiently to permit their being taken as a unit to the assembly section after removal from the jig. Here the spar booms are laid out on trestles and tables, and the braces attached by driving threaded studs through boom tubes and plates. At this stage, also, a number of fittings which are to support various gear and equipment are attached to the spar.

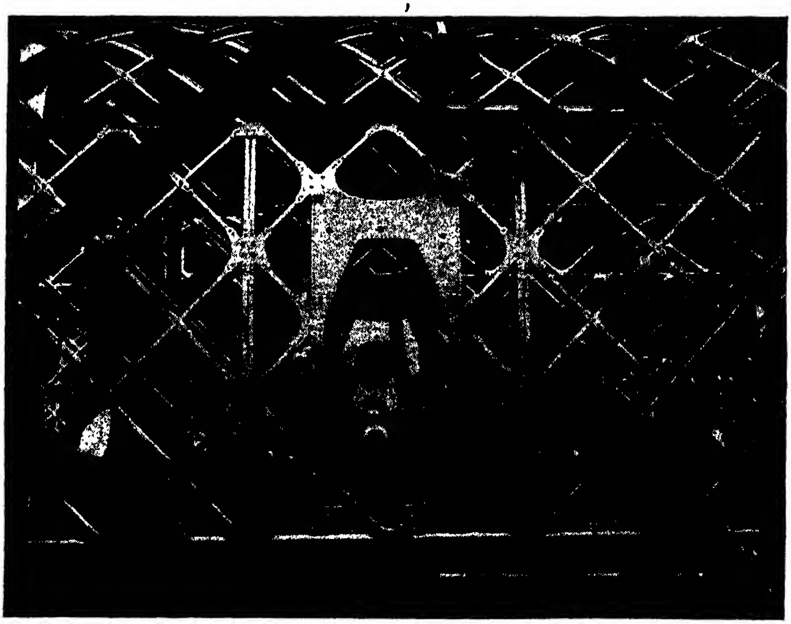


Fig. 218.—A view through several fuselages, arranged with the openings for the main wing spaces in line.

Wing Erection

In the wing-erecting shop the wing spars, geodetic panels and all the equipment and tanks which are carried inside the wings, are brought together and assembled. The main spar, as explained above, has been very carefully assembled, with lugs and bolts at the points where joints occur very carefully located and finished.

The actual trueing-up of the wing is done during the assembly by holding the roots of front and rear spars in special jigs, and drilling through boom tubes of the spars. The geodetic wing panels have been covered with fabric and doped, after which they are transported by an overhead conveyor to the wing assembly shop.

Attachment of the wing fabric is partly by stitching and partly by wiring, the latter being employed where the air loads are particularly great. First a double wire resembling an insulated electric cable, but with a web of fabric connecting the two, is slightly doped to the flanges of the geodesics. The wing fabric is laid over the top, and reinforcing strips are doped on to the fabric. The flanges of the geodesics have previously been drilled for the wiring bolts, and these are now pushed through fabric

and metal, the single wire threaded through the holes in the bolts, and the nut on the inside of the flanges put on and tightened up. Finally, strips of fabric are doped on over the wires.

When all the equipment has been installed inside the wing, this is finished off by covering the gaps which were left at the edges of the geodetic panels, and the wing is given its coat of camouflage paint before being passed to the final erecting shop. Here it is assembled to the centre-section, which has in the meantime been attached to the fuselage.

Interchangeability Tests

Interchangeability must be of a very high order. Every wing is tested, before going to the final erecting shop, on a special interchangeability gauge in which the accuracy of the wing root fittings are checked for pitch and alignment.

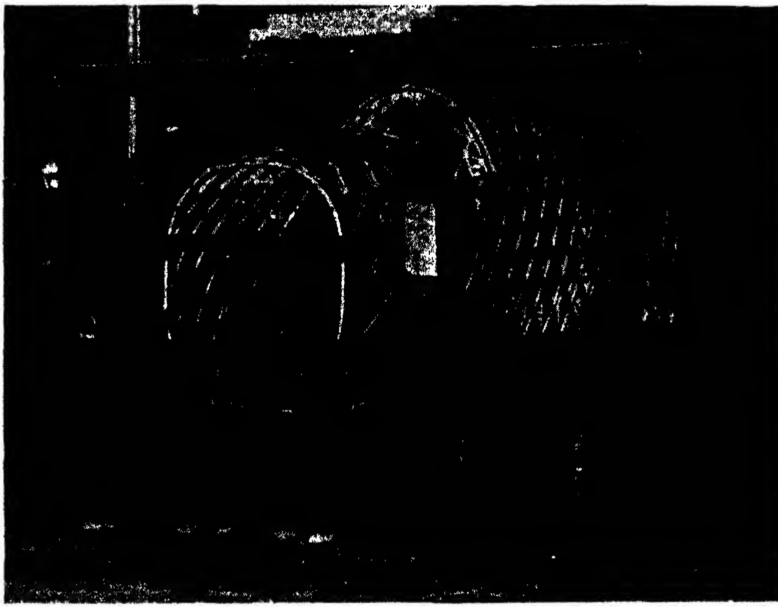


Fig. 219.—A Wellington fuselage in process of assembly in its special erecting jig.

Fuel tanks in the Wellington are made by the de Bergue riveting process. The shape of the wing tanks used is such that considerable care has to be taken to see that flexing of the wings does not cause trouble. For this reason they are built in sections and supported on the wing structure on Silentbloc mountings. A special jig is used to ensure the correct location of these mountings. Fuel tanks are also carried in the engine naeelles, but these are of more orthodox shape. The actual manufacture of the tanks does not differ from that found in other works, and is not peculiar to geodetic construction, so that there is little need to go into detail in describing it. It may be added, however, that the fireproofing of the tanks is carried out in the Vickers-Armstrong works.

The engine nacelles are not in themselves of geodetic structure; their design is governed to some extent by the fact that the three wing spars pass through them, and that two of these, the front and rear spars, are attached to them in such a manner as to make the nacelles a part of the primary structure of the wing.

One consequence of this is that the engine nacelles have to be made with particular care, and to a high degree of accuracy. To ensure this, the nacelle jigs are very sub-

stantial structures, and even so there is some risk of their becoming out of truth after a period of use. To avoid this, special reference gauges, built up from structural steel sections, are used periodically for checking the truth of the jigs.

Split Construction

The nacelles themselves are built in port and starboard halves. This system has the advantage that the installation of engine equipment such as necelle tanks becomes much easier, as all parts of the unit are accessible. After leaving the jigs, the two halves of the nacelles are brought together in a final assembly jig where they are joined, and the engine mountings, engine accessories ring and other items are attached and installed. The nacelles are then taken to the final erecting shop, where they are attached to the wing centre-section in readiness for the reception of the outer wing portions.

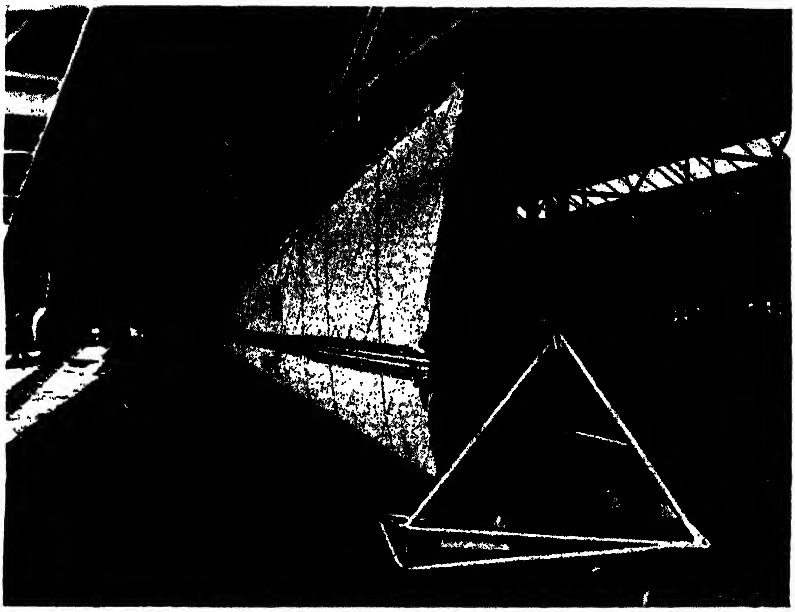


Fig. 220.—Wings on trunnion mountings are transported about the shop on wheeled jacks.

After being manufactured in various sections of the works, the different units come together for final assembly in the erecting shop which adjoins the fuselage shop. Attachment of the inner wing portions to the fuselage constitutes the first stage. The "floating" main spar has a bolted joint on the centre line of the aircraft and projects outwards through the large openings in the sides. Leading edge and rear spars, on the other hand, are attached to the fuselage main spar frames by cardan joints.

When the spars have been bolted to the fuselage frames, the next operation is to attach the engine nacelles, which are built into the wing structure and form part of it. The pointed tail and fairing of the engine nacelle is bolted to the rear wing spar, and the bolted joints of the front and main spar attachments are located inside the nacelle. When the wing spars have been attached to the fuselage, and the nacelles to the outer ends of the centre-portion spars, the undercarriage units are attached. From this point onward the machines rest on their own wheels, and can be moved about in the shop as desired.

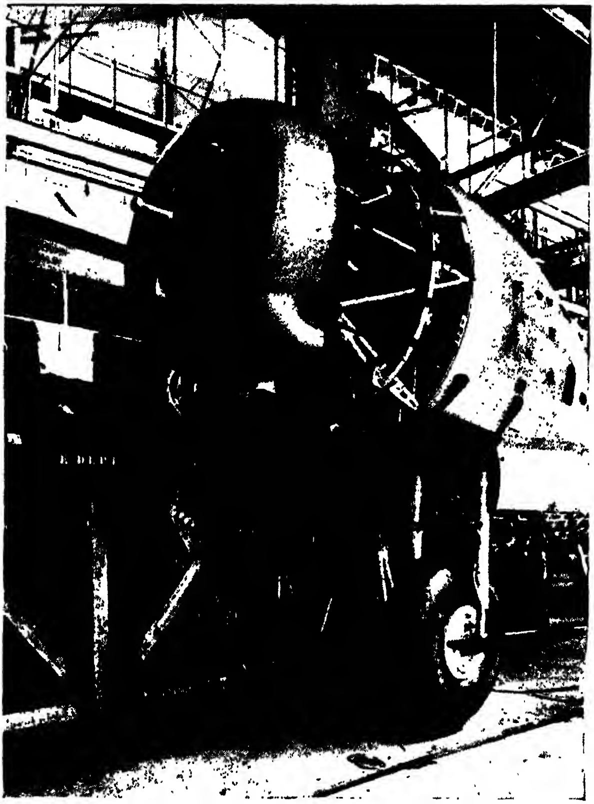


Fig. 221.—The wing centre section in place on the fuselage with the engine nacelle and undercarriage attached.

After being completed and covered in the wing shop the outer wing portions are brought by a Royce overhead crane to the erecting shop, where they are lowered into line with the fittings on the engine nacelles. Lead weights are placed at the wing tips to balance the outer wing portions while they are being transported by the crane, so that the inner ends of the wings can be lined up fairly easily with their bolted joints on the engine nacelles. When these attachment bolts are secured, the wing is released from the crane.

Engines, complete with their mounting rings, are now brought along from the section of the works in which the engine units are assembled, or from the stores where those of them are kept which have been made "outside" by sub-contractors.

When the engines have been bolted to the attachment points on the fireproof bulkheads, and final touches have been given to the fairing in of wing-fuselage joints, the remaining equipment is installed, and the machine is taken into the last bay of the building, separated from the works proper by sliding doors, for running-up the engines. The engines can thus be run-up and thoroughly tested irrespective of the weather.

PRODUCTION OF A FLYING BOAT

THE SHORT SUNDERLAND

By S. W. HISCOCKS, M.I.Mech.E. M.I.A.E., F.R.Ae.S.

DESIGNED for long-range reconnaissance, patrol and bombing duties, the Short Sunderland is a flying boat of the high-wing cantilever monoplane type.

Construction is based on that of the highly successful C-class Empire boats, though there are certain interesting differences. For instance, the rear step is faired away into a vertical knife-edge in contrast to that of the Empire type, and the pilot's control

Fig. 222.—Nosepiece of Sunderland.

cabin is set farther back from the bows to make provision for the retractable forward gun turret. Frise ailerons and Gouge electrically operated flaps are fitted.

Four Bristol Pegasus XXII engines comprise the power plant. These are mounted in nacelles of monocoque construction and drive three-bladed, two-position de Havilland airscrews. The Pegasus XXII engine has a rating of 810–850 h.p. at 4,000 feet with a maximum of 875–915 h.p. at 6,500 feet. Power available for take-off is 1,010 h.p.

It should be borne in mind, when considering the detail design and the production methods used, that orders for aircraft of the size of the Short Sunderland are received in small batches only. From a manufacturing standpoint, the detail design is

extremely simple and straightforward. The various detail parts do not necessitate elaborate tooling, and actually quite a number of standardised universal tools, adjustable to suit various sizes of similar sections, are used not only to produce parts for the Sunderland but also for other types of aircraft designed and made by Short Bros.

The system of design employed enables the various shops to commence manufacture of the various details without the delay usual with types of more complicated design. It also leaves the tooling staff free to proceed quickly with the design and manufacture of the jigs required for assembly process.

Hull

Aluminium-coated light alloy to D.T.D. Specification No. 275 is used throughout for the construction of the hull. Vertical frames of channel section interconnected by **Z**-section stringers, equally spaced, form the framework. Sheeting is riveted on longitudinally, with the vertical laps staggered. All laps and seams are joggled to give a flush exterior finish, and all rivets are countersunk in the outer surface of the sheeting, which is anodically treated before being riveted in position.

A number of watertight partial bulkheads are provided. They are of such a height as to permit any one compartment being flooded without overflow into those adjoining. Parts of these bulkheads are hinged and are normally swung out of the way to provide a reasonable gangway.

The first step in the construction of the hull is to lay out full size on a table the various sections at which the bulkheads and frames are placed, marking in the various members, bolt and rivet holes, etc. Detail parts of a size capable of being so dealt with are made on the machines in the press shop by folding and pressing. For the other parts, which are generally larger and of a more complicated shape, the alloy sheets are cut out by hand and knocked up to shape on metal formers, flat bar templates being used for the trimming of the ends and for drilling purposes.

Assembly of the bottom portion of the frames and the ordinary bulkheads is carried out on the bench without jigs. Side and top members are assembled to the bottom section on the laying-out table and checked for truth before being taken off to be riveted together, plus or minus one-sixteenth of an inch being allowed on the overall dimensions. Similar methods are practised for the construction of the keel.

At the points where the main wings are fixed to the hull there are two much heavier and more complicated bulkheads. The parts for these are made up as detail and sub-assemblies, as with the other bulkheads, but are assembled in larger vertical jigs.

In the first pair of jigs, the overall size and shape of the bulk-head is controlled. First, the bottom frames are placed in these jigs and dowelled in position; then the side posts are also dowelled and attached to the bottom frames, after which the top member is added and attached to the side posts.

Panel bracing members, having already been assembled as sub-units, are then placed in position, and the brackets attaching them to the side posts and bottom frames fitted and attached. After this sheeting and stiffeners are fitted and riveted in place. These bulkheads are then taken out of the first jig and placed in a second jig, which is provided with locating points for picking up the wing roots on the ends of the centre-section wing truss, and also for the attachments to take the beaching chassis.

Next, the centre-section truss is placed in position in the jig, all connecting bolt holes drilled and reamed in position, and the bolts fitted. Following this, the bulkheads are taken out of the second jig and slung vertically, while all rivets not accessible in the jigs are put in and closed down.

For ease in construction, the hull is built up in two portions. The main portion extends from the nose to just in front of the tailplane, and the rear portion from the leading edge of the tailplane to aft of the rear gun turret.

Dealing with the main portion of the hull, the first operation is to set out and paint lines on the floor for the stations of various frames and bulkheads. The lines for these stations on the top profile board and the keel board are then checked up from the floor.

The keel is now mounted on the keel board and held in position by means of clamps and bolts passing through the lightening holes in the keel. The joint frame at the aft end of the main portion of the hull is placed in position and tied to the main gantry framing by means of special stays which secure it in a square and upright position. This joint frame forms a datum from which all the other frames are lined-up. These are now lowered into position on the keel and temporarily attached to it and to the top profile board. When they have passed inspection for alignment they are

riveted to the keel. Temporary, longitudinal angle-iron spacing bars, fitted at intervals circumferentially, are used to keep the frames true and in their correct relationship prior to the fixing of various stiffeners.

Longitudinal stiffeners of **Z**-section, received in rough lengths from the press shop, are cut to length in a jig and have the holes drilled to take the angle-plate fixings to the frame. These angle plates are pressed out with the rivet holes in them ; stiffeners and angle plates are then bolted in position to the frames.

Flat, pressed-out plates are now fitted to tie the stiffeners together across the inside of each frame, the frames and stiffeners being drilled from the holes in the tie plate. Angle plates are used to tie the stiffeners to the bulkheads.

Stringers of a very shallow " top hat " section are placed circumferentially between each frame or bulkhead. They are fixed to the inner surfaces of the longitudinal stiffeners and are used to tie them together.

Fig. 223.—View looking forward in an unfurnished pilot's cockpit. Bulkhead forward separates cockpit from front gun turret which retracts aft to facilitate mooring operations. Master fuel cock control levers, fuel jettison and tail trim controls are situated centrally in the coupé roof.

Coamings for port holes, doors and hatches, made as separate units in jigs, are assembled to the frames and stiffeners at this stage, as also are the inner chine angles. After this all the above-mentioned items are riveted together and inspected prior to sheeting ; after passing inspection, the whole skeleton framework is painted inside and out with chromate paint.

Sheets for the skin are supplied in stock sizes to the shop, where they are cut approximately to the required dimensions. Each stiffener has three location holes drilled in it, one at each end and one in the middle. The skin sheets are clamped in position and the location holes drilled through from the stiffeners, as also are the

holes for the rivets joining the skins to the various frames. The sheets which form the skin are of a size to cover some two to three frames and three to four stiffeners.

After the sheets have been drilled they are taken down, and the remaining rivet holes for fixing them to the stiffeners are drilled on a bench. Wooden spacing-strips are used to mark out the pitch. Duralumin rivets ⅛ inch in diameter are employed on the stiffeners on the top portion of the hull, and 5/32 inch diameter for all fixing to other stiffeners, frames, and bulkheads. The pitch of the 5/32 inch diameter rivets is 1¼ inch normally, and ⅝ inch where watertight joints are required.

Skin sheets are now re-positioned on the hull skeleton, held by tack bolts, and all remaining rivet holes drilled through from the sheet to the stiffeners. They are then taken down and the edges of sheet and holes are removed.

Sheets of 20-gauge thickness are used for the top skinning, and the thickness increases gradually downwards to 16-gauge for the bottom sheeting. Sheets of a thickness less than 18 gauge have the rivet holes in them, the corresponding stiffeners being dimpled on the bench under a deep-throated machine, and the stiffeners in position on the hull by a hand tool. In sheets of 18-gauge thickness and over, the holes are countersunk in the metal to take the flush rivet heads. Rivet holes in the frames and bulkheads, to which the dimpled lighter gauge sheeting is fitted, are countersunk by means of a Desoutter countersinking tool.

After removal of the burrs the sheets are anodised, and during this period all the joint surfaces on the skeleton frame are painted with Duralac. This is also applied to the joint surfaces on the sheets after anodising.

Sheets are now put back on the skeleton frame and held in position by means of tack bolts. Tack rivets are put between the bolts, which are then taken out, and all remaining rivets put in and closed down. Consolidated one-shot guns are used for the majority of the rivets.

When sufficient sheeting has been riveted in position to hold the structure rigid, cradles are fitted to take the weight of the hull. Keel and top profile boards are dismantled, the keel plates and cover strips fitted, and also the top profile plates and the outer chine angle.

After passing inspection, a water test is then made by spraying the inside of the bottom of the hull with a stream of water under pressure from a nozzle and examining the outside for leaks. Two coats of paint are then sprayed on the inside of the hull, one of chromate and one of either silver or green. Silver is used generally, and green at such places as the pilot's cockpit and gunners' stations. Various internal items are now fitted, such as the upper deck, lower floor bearers, access ladders and numerous brackets.

After the hull has again been checked for alignment, a trolley is placed under the spar frames and adjusted to take the weight of the hull. The cradles are then dismantled, and the hull sent into the final erecting shop.

Prior to the fixing of the stiffeners and sheeting, two heavy metal jigs are fitted to the hull, one on each side, to locate the wing attachment fittings in their correct positions. The relative position of the two jigs is checked for alignment from the floor. Channel iron jigs are also used for locating the position of the attachments for the beaching trolleys.

At certain portions of the hull, the skin sheets require shaping to fit the frames. The sheets are formed to the required shape by hand on a wheeling machine, wooden jigs being used for checking purposes.

The rear portion of the hull is built up by methods similar to those used for the main portion. The size of the rear portion, being relatively small, permits the use of a combined metal jig built up with a gantry to locate the positions of the four tailplane attachment points on the sides of the hull, and also fin attachment points.

After the rear portion is completed it is taken out of the gantry and the fin and tailplane fairing strips fitted. Loose jigs carried from the attachment points for the fin and tailplane locate these fairing strips whilst they are being fixed. This rear portion of the hull is finished off in a similar manner to the main portion, and is then sent to the final erecting shop.

Wing Tip Floats

Aluminium-coated light alloy to D.T.D. Specification No. 275 is used for the wing-tip floats. The floats are flush riveted in the same manner as the hull. Each wing-tip float is slung from the underside of the main plane by two tubular struts suitably braced.

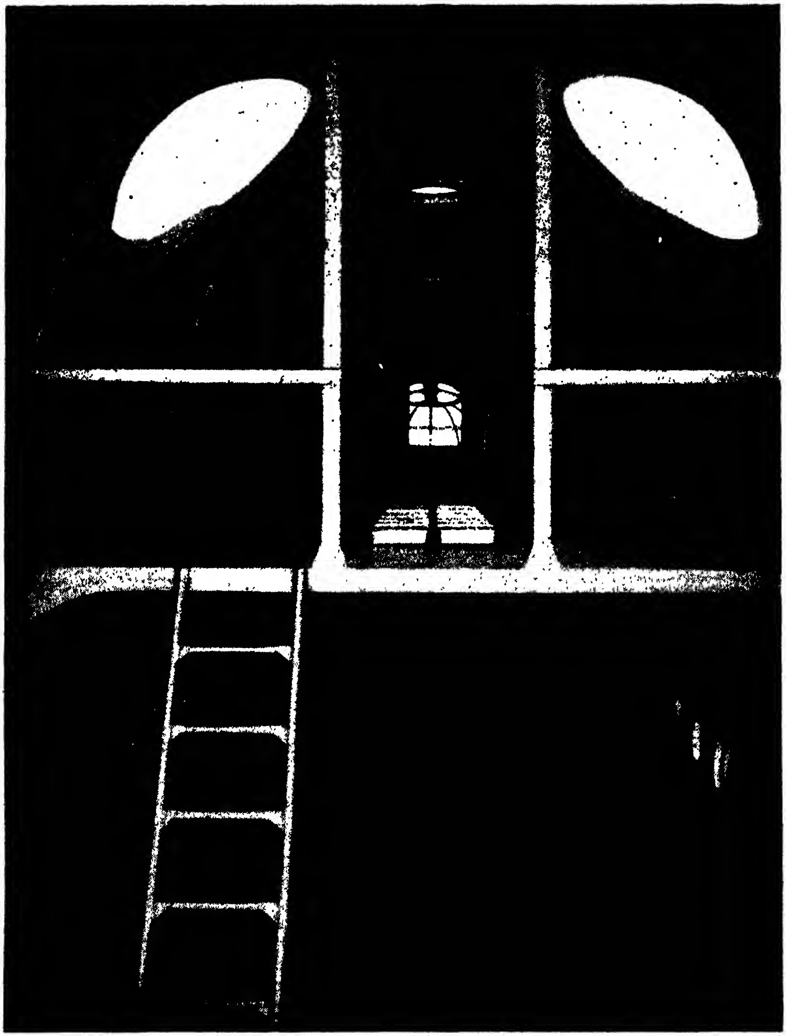


Fig. 224.—Interior constructional view looking forward from a position just aft of rear entrance hatch. Transverse frames of channel section above chine and "2" section below are interconnected by longitudinal "2" section stiffeners. Upper and lower decks are clearly illustrated in this picture and generally illustrate the roominess of the hull. The bulkhead on the lower deck separates the bomb compartment from the crews' quarters. Above this is shown the two pintle mounted mid-upper gun positions.

Each float has four watertight bulkheads and six frames. Bulkheads are made up from flat sheet cut to shape and have the edges flanged over. The surface of the sheet is stiffened by means of V-section members riveted in place.

Frames are built up of a number of channel sections riveted together, both frames and bulkheads being made up as sub-assemblies. When completed they are placed upside down in a wooden cradle in their correct relationship, levelled, and checked for alignment. The keelsons are now fitted and are connected to the bulkheads by angle cleats, and to the frames by tie plates on the inside on the framing.

The bottom sheeting, keel cover strip and the internal and external chine angles are then fitted. Bottom sheets overlap on the vertical face of the step on the bottom of the float. After the sheeting has been riveted in position the structure is taken out of the cradle and put the right way up into a second cradle.

Troughs for the strut ends are fitted and then all frames are lined up; metal jigs are dropped into the troughs to hold them true, and temporary diagonal stays fitted to hold trough bulkheads in their correct relative position to the keelsons. Temporary angle-iron spacing bars are used to position remaining frames true with the trough bulkheads.

Diagonal and longitudinal side and top stiffeners are then fitted, and also the trough brackets taking the chassis struts. Sheeting is now carried out in manner similar to that employed for the main hull, there being two strakes on each side. The sheets are drilled from the inside members, joggled where necessary, and the rivet holes dimpled to give a flush finish.

Manhole covers in the top are secured to a beechwood strip coaming by means of wood screws. Palmer rings are used for the hand-holes, the trough covers being held in place by means of Simmonds nuts and screws.

Each bay is filled with water to test the float for leaks, and after passing inspection the interior is given three coats of paint and the exterior two coats, the finish being silver in each case.

Main Planes

Each main plane is built up round a spar which consists of four T-section Hiduminium extrusions, two at the top and two at the bottom corners. The outer surfaces of the flanges of these extrusions are finished to line up with main plane profile.

Top and bottom booms are braced together vertically and diagonally by means of duralumin tubular struts to form complete front and rear trusses. In plan, the two trusses taper towards the wing tip and are connected together by drag members of the shape of the wing profile. These are built up from smaller extruded sections and light alloy sheet.

The leading edge is made up of a series of shaped nose diaphragms, and the trailing edge wing portion consists of ribs having extruded section booms, with tubular bracing members; the wing tip is a detachable unit.

At the root end of each wing, and between the spar trusses, are housed three fuel tanks. Holes are cut in the top skin of the wing to allow entry of these, and when the tanks are in position the holes are filled in with flush-fitting stressed-skin covers. Each tank rests on a wooden grid fitted between the spar trusses.

Aluminium-coated light alloy to D.T.D. Specification 275 is used for sheeting the main planes. Overlapping joints of the skin are joggled and the riveting is countersunk to give a flush external surface.

Each spar boom consists of three lengths of T-section extrusion, the dimension and thickness varying from about 6 inches by 5 inches by $\frac{3}{4}$ inch thick at the root end, to about $1\frac{1}{2}$ inches by $1\frac{1}{2}$ inches by $\frac{1}{8}$ inch thick at the wing tip. These booms are machined to the design sizes from uniform T-section extrusions on special motorised horizontal milling machines, designed and made by Short Bros. and having a travelling table about 22 feet long. Taking the machining of one of the larger root-end sections as a typical example, the operations are roughly as follows:

(1) Milling web to thickness tapering throughout the length of extrusion to limits of $\pm$ 0.005 inch. An aluminium jig the length of the table holds the extrusion in place. The jig has a screw and vernier fitted at one end to adjust its position laterally relative to the cutter. One side of the web is milled first, using a 12-inch face cutter. Two roughing cuts at 180 r.p.m. and one finishing cut at 90 revs. are made with a table speed of 11 inches per minute. The jig is then adjusted laterally on the table with work still fixed to it, and the other face of the web is machined.

(2) Milling flanges to width tapering throughout the length of the extrusion, limits $+$ 0.020 inch, $-$ 0. The face of the web of the extrusion is held vertically in place on an aluminium jig the length of the table on a machine similar to that used for operation (1). One edge of the flange is first machined, then the jig is adjusted laterally, and the other edge machined.

(3) Milling flange to thickness tapering throughout length of extrusion, limits $+$ 0.015 inch, $-$ 0. The same machine and jig are used as in operation (2). The jig is lifted at one end, and has adjusting screws to take its weight at intervals throughout its length. The flange is then milled to required thicknesses.

(4) Milling web to required depth, varying throughout length of section, limits + 0.020 inch, − 0. The same machine and jig is used as in operations (2) and (3), the jig being lifted at one end to give the required tapering depth of web.

After machining, the blending of the radii at the roots of the web is finished by hand on a bench. Top surfaces of the flanges are then scraped and filed by hand, to give the varying slight curvature needed to enable them to blend in with the wing profile.

Next the extrusions are cut to length, fitted into a jig, and the joints made which connect the three lengths of varying section machines extrusion into one long boom. The butting surfaces of the extrusions are filed and scraped so that, when fitted together, the surfaces do not have a gap of more than 0.0015 inch at any one point.

Pre-drilled machines cover plates to the webs and flanges are fitted at the joint, the webs and flanges being drilled and reamed from the cover plates. Countersunk-headed bolts are used for the flange joints and hexagon-headed bolts for the web joints.

Gusset plates to secure the bracing members are then positioned in the jig by two locating holes. Following this the two plates, the web of the extrusion, and the end fittings in the vertical and diagonal bracing members are drilled from a jig plate, one of these being provided for each joint.

Fig. 225.—View looking aft from a position adjacent to the radio operator's station showing accumulator charging panel mounted on the front spar frame. Accumulators are stowed on the floor to the port side of the centre section.

Duralumin tubing is used for the vertical and diagonal bracing members. End fittings are machined from an extruded section of special shape to the tubes. This gives access to the rivets which secure the fitting to the tube. The tube ends are slotted for the same purpose, and the tubes and their end fittings are assembled together as distinct units in separate jigs. Stainless steel hollow rivets are used for fixing the fittings to the tubes, and duralumin rivets for attachment to the gusset plates.

A portable motorised radial drill mounted on casters is used for drilling holes in the gusset plates and webs. The machine has a screw-jack at each of the four corners of its base. When actually drilling, these jacks take the weight of the machine while they are also used for levelling up.

Flat-strip metal templates are laid along the outside of the boom flanges, and the sheeting rivet holes are marked off from these by a centre punch. After dismantling from the jig, these holes are drilled in the boom flanges under a fixed drilling machine.

For the final assembly of the wings the main truss is placed on trestles and levelled up. Trailing-edge ribs are fitted and fixed to the rear spar, and the inner hinge rib for the flaps is set to its correct position in the wing by means of a triangular jig picking up from the rear spar. Angle-iron spacing bars are used to set the remaining ribs true to the inner hinge rib.

Z-stiffeners between the ribs are then fitted, and the rear portion of the wing covered with sheeting in the usual manner, following which the four flap hinge arms are fitted. Jigs are used for levelling and setting.

Engine nacelles, made up as separate units, are now fitted to the front spar. At this stage, too, the wing tip, the fixed portion of leading edge, and the maintenance platforms are fitted. After painting, which is carried out in the same shop, the ailerons and flaps are fitted. Trestles on which the wings are assembled are mounted on wheels, the assembly being moved on these trestles across the shop floor to the crane to be lifted into place on the hull.

Fig. 226.—View looking outboard from wing root showing general construction of main plane. Upper and lower booms of front and rear lift trusses are formed of " T " section light alloy extrusions braced with tubes of similar material. Built-up drag members conforming to the wing contour connect these trusses, twin wires providing incidence bracing. Leading and trailing edge portions are assembled separately, the latter constructed to house the Gouge type flap.

Tailplanes

Whilst the construction of the tailplane is somewhat similar in design to that of the main planes, the methods used for assembly are rather different.

T-section extrusions are used for the top and bottom booms of the spars. These are machined to size on a Parkson horizontal milling machine, the table of which has a travel of 11 feet. The booms are then fitted into a jig on the bench, and have the various gussets, angle pieces and wing root plates fitted.

After this the booms are placed in position on a vertical jig, which is designed to deal only with the assembly of the top or bottom surfaces of the port and starboard tailplanes. That is to say, a jig for top surfaces only is used for assembly and riveting up the top booms, top drag members, top stiffeners and top sheeting. The methods for fixing the stiffeners, the sheeting and the riveting are similar to those used on the main plane.

Top and bottom surfaces of either port or starboard wing are placed together in a main assembly jig after being taken out of the surfacing jig. Here they are located at the root ends and at intervals throughout the length of the booms.

Duralumin tubular vertical and diagonal members forming the front and rear bracing members are fitted in position to the top and bottom booms of the spars. Pre-drilled elevator hinge plates are then located in the jig, the rivet holes in the brackets on the boom are opened out and the plates riveted in place.

Wing tips and leading-edges are made up as separate units, and the method of construction is similar to that adopted for those on the main planes. These items are now fitted; a loose angle-iron jig is located on the main jig for the purpose of drilling the holes in the booms which take the bolts holding the leading-edge in position. The skin of the leading edge is riveted to the main truss skin for a short distance at the root and tip ends only. A major portion of the length of leading-edge skin is joggled into a recess left between the main truss skins and the top and bottom front spar booms.

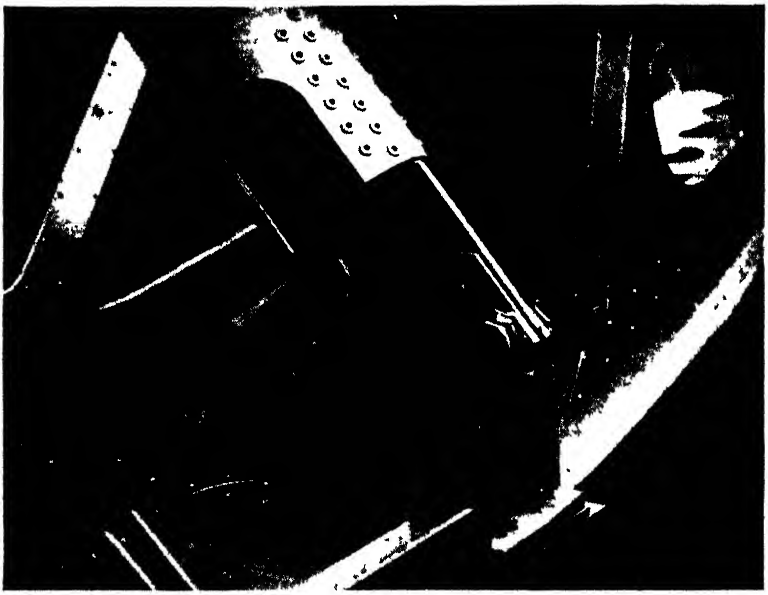


Fig. 227.—Close-up of main plane root joint. Connection to centre section spars is made with " T " section steel forging, the web of which picks up between the side plates shown and is then forked to fit web of centre section spar member. Forging flange sits on top of and is bolted to spar flange.

Elevators

Building up of the elevator leading-edges is similar to that of the tailplane leading-edge, with the exception that the assembly jig has throw-over clamps to hold the sheet cover to the ribs. These clamps act as drilling jigs for the rivet holes in the sheet and ribs. There are no longitudinal stiffeners in this unit under the skin.

The skin is anodised and riveted to the ribs, the front and rear spar members being then fitted. They consist of rectangular pieces of sheet flanged on all four edges, and have flanged lightening holes in their surfaces. These members are located between each rib; holes are drilled for rivets and members riveted in position.

The leading-edge is now placed in a jig which has throw-over locating points for the elevator hinge brackets. Hinge plates and supporting channels are fitted, and the holes drilled to take the ball race housings. Following this the torque tube is fitted, there being a locating point on the jig to position the flange collar on the tube end.

Trailing-edge ribs for the elevator are made up as separate units. They have a sheet web with flanged lightening holes, and two small extruded angles on each side of the web at the top and bottom to form the booms. These ribs are placed in position on the jig and fixed to the leading-edge. The trailing-edge, of **V**-section, is fitted, and the two inner ribs covered with sheet.

Fabric is used to cover the rear portion. At its front edge this is held to the leading edge by a metal strip secured in place by small bolts, the fabric being sewn to the ribs and trailing-edge in the usual manner.

The methods used to construct and build up the ailerons, flaps, rudder and fin are similar to those described for the other units and do not call for any special comment.

Engine Nacelles

Built into the leading-edge of each wing are two circular engine nacelles of monocoque construction. Each nacelle is formed by seven frames interconnected by **V**-section skin stiffeners, and completely sheeted with light alloy.

Sheets of 16-gauge material are used for the frames, cut to size and flanged to channel section and required curvature on formers by hand. The covering is of 19-gauge sheet beaten by hand to the required curvature and finished by wheeling. A spinning from 14-gauge material forms the engine ring. All detail parts are made up on separate jigs. They are then placed in an assembly jig, fitted and riveted together, the various holes cut in the sheeting and the edges strengthened. The brackets for the hand starter are also located and fixed in this jig.

Fig. 228.—View showing starboard inboard nacelle with engine and exhaust ring mounted. Enclosed in a fireproof compartment and accessible from the main engine maintenance platforms (not fitted in this view) is the auxiliary power unit which provides for refuelling, electrical generating and bilging when afloat.

On the nacelles the contour boundary frames are made from 14-gauge sheet, knocked up to shape on metal formers. The frames are then placed in another assembly jig and connected together by the secondary frames and skin stiffeners. After riveting together, the aerofoil sheeting is first fixed, then the top and bottom sheeting, and the fillet angle between the engine body and the aerofoil section.

The nose is now offered up to the nacelle and held in position by temporary bolts. The complete structure is taken out of the jig and the joint between the nose portion and the nacelle riveted up. Fitting of the fireproof bulkhead and the remaining stiffeners and sheeting follows, also that of the Exactor control brackets, and the top after fairing from the nose to the wing.

Fuel Tanks

Fuel is carried in six tanks, three in each main plane. Each of the inner pair has a capacity of 529 gallons, the intermediate 355 gallons each, and the outer pair 132 gallons each. Construction is similar in all cases.

All tanks are made from aluminium-coated light alloy, the inner tanks having shells of 18-gauge thickness and the other two 20 gauge; the top and bottom ends of all are of 18 gauge.

Shells are cut to size and after anodising are rolled to shape. They are made from two or three pieces of sheet riveted together and stiffened by two angles spaced between the ends and riveted in place.

Top and bottom ends are made in two pieces. These are flanged on a Selson flanging machine, drilled to template, anodised and riveted together. Reinforcing patches for fittings and stay tubes are also riveted on. The top end is first fitted to the side shell and an angle-iron jig bolted to the bottom edge of the shell to maintain its shape. Two stiffening angles are now fitted, and the tank lifted by the angle-iron jig, whilst the top edge is riveted by a de Bergue riveter. After this the tank is lowered, turned over and lifted by the top end, and the stiffening angles riveted to the shell.

Cross-shaped baffles are now fitted to the tank. These baffles are made up of the same material as the shell, with a number of stay tubes clipped in place, and assembled as a separate unit in a jig. The stay tubes are of duralumin, and have stainless steel screwed plugs riveted in at each end. Remaining stay tubes, which are not fixed to the baffles, are also fitted.

The bottom end is now put in, tightened up to the stay tubes, and then riveted to the shell. All tanks are tested to 1½ lbs. per sq. inch pressure, then washed out and painted inside with two coats, one of chromate and one of silver.

Two-ply fabric is used for jointing in the seams, and Heldite for the joints of the fittings.

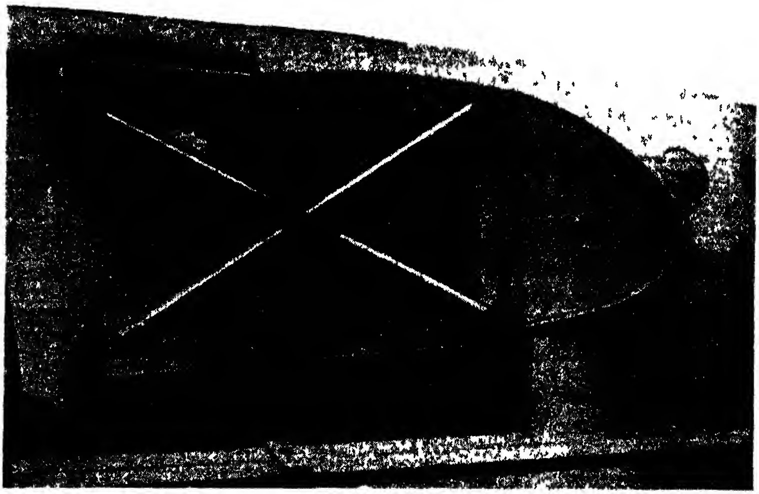


Fig. 229.—Exterior view of hull centre section, showing wing main attachment points. "T" section members similar to wing spar booms continue through hull and are tubular braced. Special top-hat section stiffeners on hull side provide drag bracing. Access to interior of wing from hull is possible during flight.

Erection of Complete Aircraft

The first operation is to level up the main portion of the hull on its handling trolley, which has four screw-jacks at its corners for this purpose. The aft portion of the hull is then fitted to the main portion. "Biscuits," or joint plates, on the wing attachment points are now bedded down on to the forgings on the centre spar trusses. The wings, which have had the engines, cowling, pipes, controls, etc., fitted on the floor, are lifted by the overhead crane into position on the hull, and are jacked up to the correct angle.

Next, jig plates are fitted to the booms of the spars. Holes are drilled and reamed, vertical holes in the booms being dealt with first. After removal of the jig plates the

biscuit plates are refitted and reamed in position. The joints are then bolted up, the wing fillets, tailplane, elevators, fin and rudder fitted and jointed to hull. Subsequently the following units are fitted: beaching chassis, wing-tip floats, struts and bracing, all flying and engine controls, gun mountings, bomb gear, instruments, wireless, airscrews and all other equipment.

After inspection and checking of petrol flow the aircraft is pushed out of the shops on to the slipway, and the engines are run up and adjusted if necessary.

All doors, portholes, etc., are tested for water-tightness by means of a jet of water under pressure. Water is placed in the bottom of the hull and the donkey engine run to test the bilge pumps. Water is also placed in the floats and the hand pumps for draining the floats tested.

SPECIALISED AIRFRAME PROCESSES

PRECISION PIPE BENDING

In addition to considerable saving in production times offered by an entirely new technique in pipe bending methods, introduced and developed by Blackburn Aircraft, Limited, holders of the patent, a greatly improved degree of precision and interchangeability of the finished parts is made possible without the use of skilled craftsmanship. Complicated forms with bends in several planes may readily be produced as accurately as simple bends.

Until the new process was worked out, the bending of many pipes required for the modern aircraft was very largely done by hand by skilled coppersmiths. Even with experienced workers the process was relatively slow, and the finished work not entirely uniform. Now, by means of the Blackburn process, pipes are bent by machine, with a high degree of precision, and the job becomes essentially one that does not call for highly skilled operatives. The process of pipe bending by the use of press methods has been developed to a point where all pipes in production quantities can now be so handled, and only experimental pipes or small batches are hand formed. The saving in time on most pieces is marked, pipes formerly requiring several hours to bend up by hand now being produced in a few minutes. Even with difficult pieces the production times, including filling, emptying, and all finishing operations common to both hand and machine work, can be cut to a third or quarter. The process is suitable for automobile, light marine and general engineering pipe work in addition to aircraft work, wherever quantities warrant the relatively inexpensive equipment needed.

Application to Aircraft Work

Pipes for oil systems, hydraulic lines, gun turrets, etc., in Tungum, Barronia metal, aluminium alloy, copper and brass may all be machine formed with success, copper responding rather better than the other materials. Steel pipes may also be handled successfully, the tools required being arranged to suit any special material.

As an example of the use of the process it may be stated that the current production aircraft Blackburn "Botha I" twin-engined bomber is entirely equipped by press formed pipes ranging from ½ inch to 1½ inches by 24*g* and 22*g*, Tungum and Duralumin, and pipes in aluminium from ½ inch to 1⅜ inches by 20*g* and 16*g*.

Bends may be simple and confined to one plane, or may be difficult in form and complex, in several planes. The length of the pipe is not limited to the size of machine in use, as the pipe can be allowed to overhang.

The Press

The bending is performed by special dies constructed mainly of wood, and these are actuated in a suitable press, either hydraulic, pneumatic or mechanically operated. The machine originally used by Blackburn Aircraft, Limited, was a vertical screw press with friction drive, driven by an electric motor of 0.5 h.p. The effective stroke is 18 inches, and as a slow, even pressure is required when producing the bends, this type of press is quite suitable. The rate of feed used is 10 inches per minute, the return stroke being speeded up to 14 inches per minute. (A faster return motion might be used to advantage if available.)

The baseplate of the press is 2 feet wide by 4 feet 6 inches long, but this is by no means the limit of size of the dies which may be used, since they may overhang the baseplate on either side.

The pneumatic press designed specially for the Blackburn process by Charles D. Holmes & Company, Limited, of Hull, is operated from the air mains, the movement of the ram being controlled by means of trip gear actuating the air slide valve. The speed of the ram can be adjusted separately for the up and down strokes. This press has proved eminently successful and is believed to be more effective than an hydraulic press.

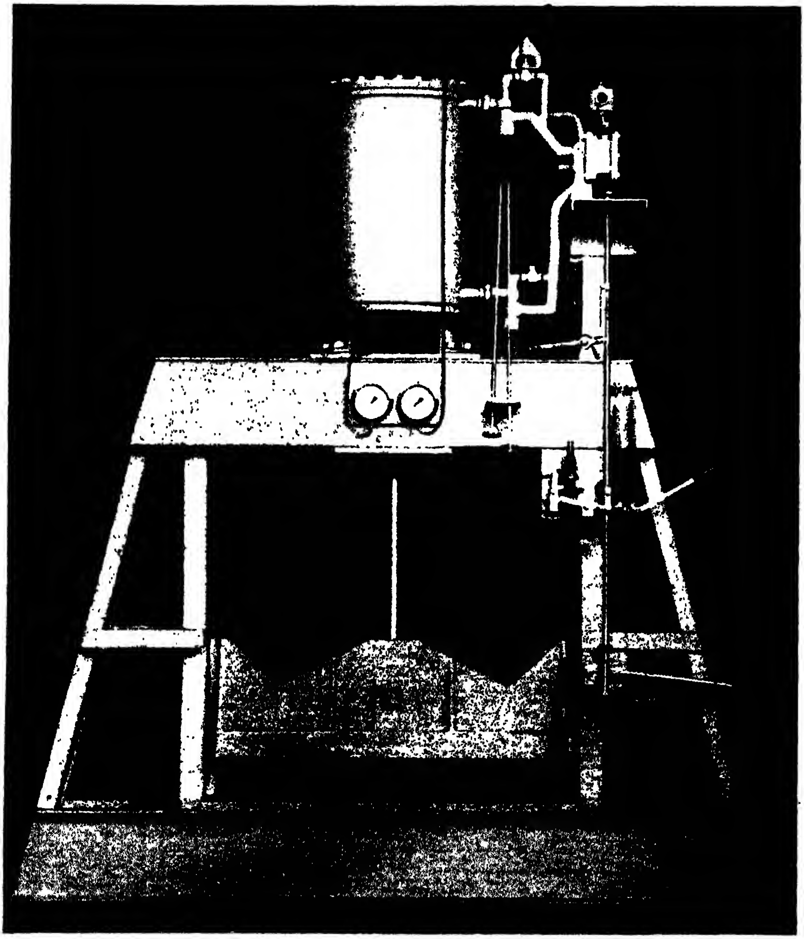


Fig. 230.—Pneumatic Pipe Bending Press by Charles D. Holmes and Co., Ltd.

Preparation of the Pipe

Before the bending operation, pipes are first prepared by being cut off to approximate lengths and squared up on the ends. Copper and aluminium are annealed before processing. Tungum pipes are worked in the condition as supplied to specification. The pipes are then filled or loaded in the normal way to prevent collapse or local puckering of the walls, as described in a later paragraph.

The Principle of the Dies used

The bends are made in the press by means of dies or jigs of severa types, designed to suit each particular piece. For all general work the press tools are of wood, and comprise " punch " and " die " arranged to slide the one in the other. Birch is commonly used in the construction of the tools, the wood being suitably reinforced at points where stress is high by metal plates, and faced by surfaces of red fibre or other hard-wearing material where subjected to heavy local pressure or wear. The two portions of the jig or die are provided with suitable registers or grooves which keep them in correct relations during the working stroke, and with clamps or fixtures to receive and locate the pipe. The contact surfaces of the jig and the pipe being bent may be greased to assist the operation.

Where the bends are of an easy character and all in one plane, a simple press tool provides all that is necessary. The two halves are cut to the form to be generated, and a stroke of the press is all that is required to complete the simple bending operation. Press bending of this simple type has, of course, been practised for some years.

Such simple pieces are, however, rather the exception, and most jobs require bends in two planes, necessitating dies constructed to form the bends by combined downward thrust and wedging action normal to the press stroke.

The next figures show the patent tools for producing a pipe with fairly simple bends in two planes. A close-up view of the tools at the start of the stroke is given in Fig. 232.

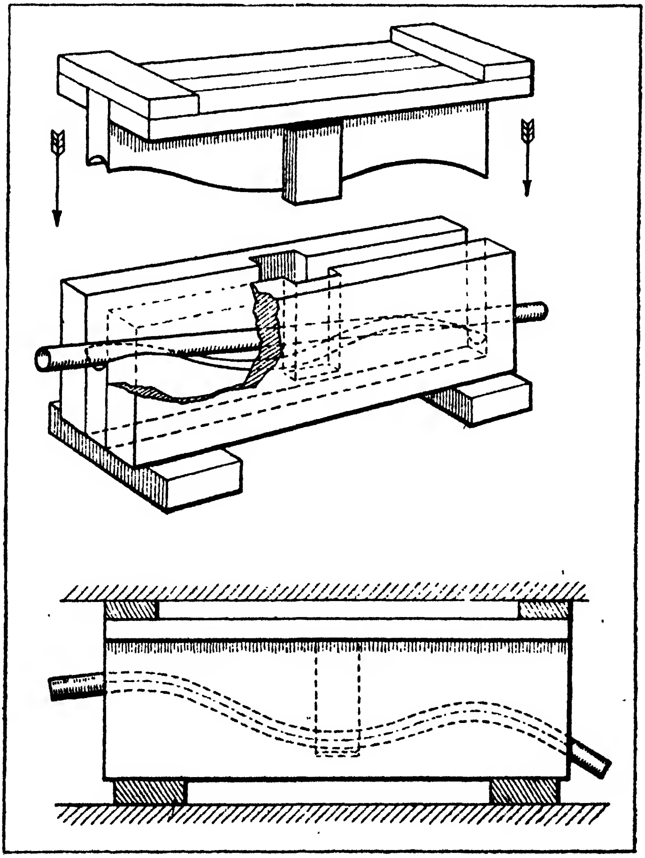


Fig. 231.—Press tools for simple bends without the use of helical-faced or cam-action formers.

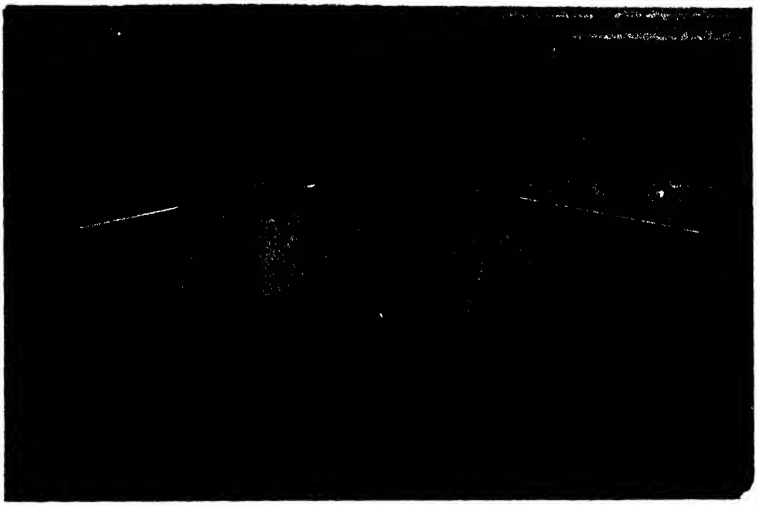


Fig. 232.—Start of bending operation with helical-faced tools.

The pipe has received a first slight set, which may be done by hand, and is held down by clamp buttons; the two spiral form "dies" are about to descend and force the ends of the pipe into the required shape. As the press ram descends, the pipe is gradually "persuaded" round the former blocks of the fixture by the helical faces of the tools, which mate in helical slots cut in the lower "die." On the return of the press ram, the pipe is left bent to shape.

Considerable use is made of the wedging action normal to the press stroke, in many difficult bends. The fixed portion of the die is in two parts, the upper part being retained in position during the working stroke by means of battens. The "punch"

Fig. 233.—The tools descending. Pipe is $\frac{3}{8}$ inch diam. 24g.

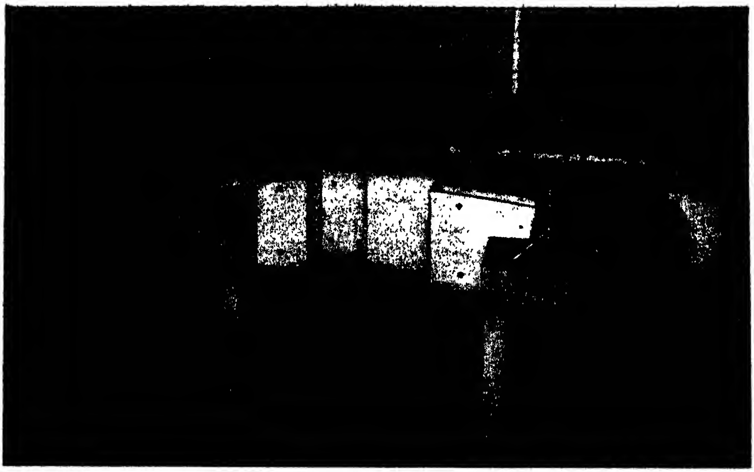


Fig. 234.—Completion of the bending operation.

consists of a number of wood blades which slide in slots cut in the upper part of the die, and which actually press the pipe down and round the formers of the latter. The bending in this example is entirely normal to the stroke, and after the stroke the die may be lifted apart for the removal of the finished part.

The use of the helical faced punch is illustrated further in the next examples; the principle is frequently employed in the production of bends of the "pot-hook" variety, which are easily produced by one stroke by this simple means. In a typical hook bend job, all bending is normal to the stroke; the formed tools slide in slots cut in the lower die, the diagrams making the bending action obvious.

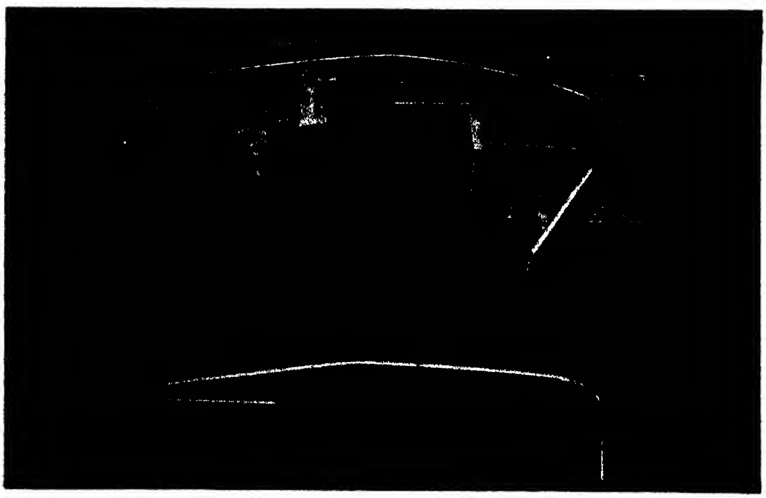


Fig. 235.—Tools withdrawn, showing finished pipe.

Double Action Dies

So far the work described has been performed by press strokes in a single plane. (The loop bend must necessarily be split into two or more operations, but these are more or less in the same plane.) A feature of the Blackburn process, however, lies in double action die working which is of great utility in many complex bending operations. Briefly, this involves the splitting of the bending into two operations, usually carried out at planes normal to one another, the same dies being employed for each operation. After completing the first series of bends, the punches and die are clamped in the "closed" position, the whole turned on its side and a second set of punches inserted in grooves or ways provided for a second operation.

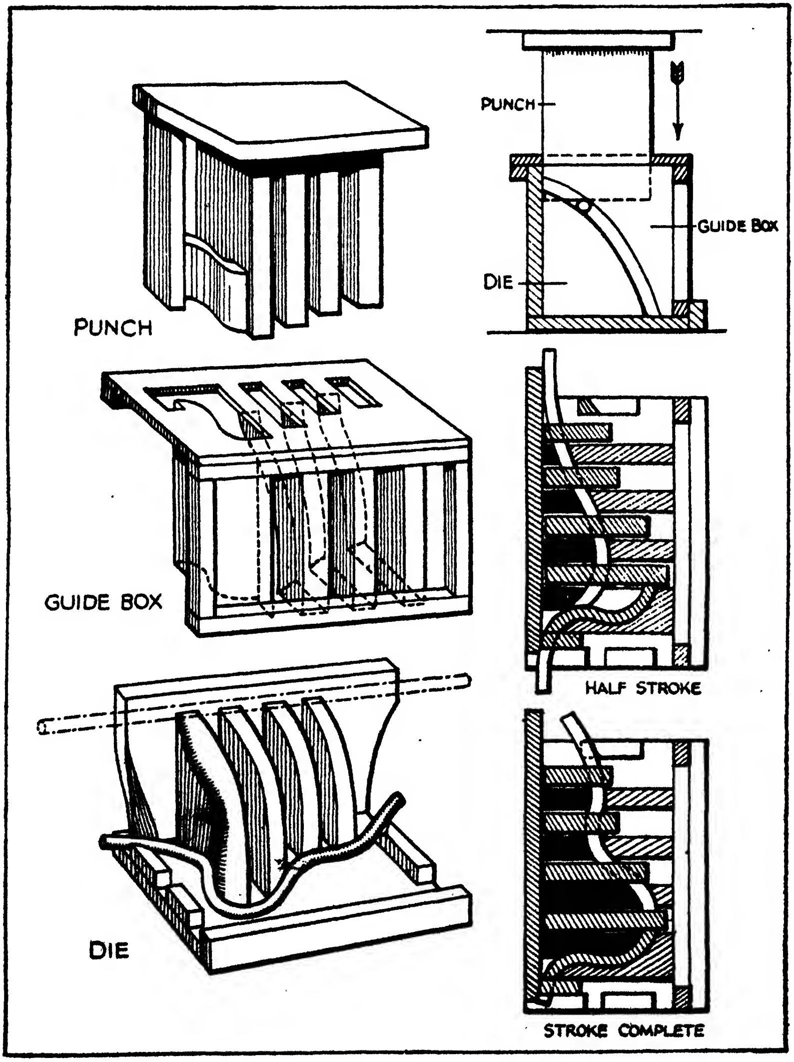


Fig. 236.—Tools for bending in plane normal to the press stroke, using wedging action.

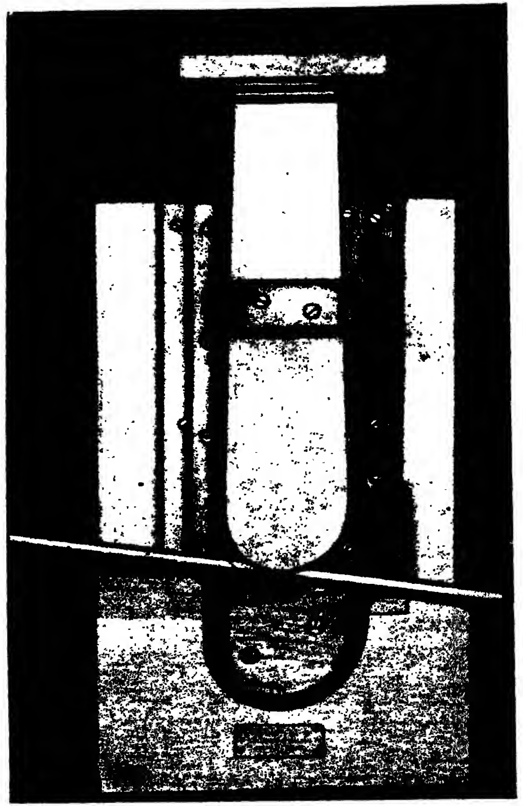


Fig. 237.—Loop bend, of more than 360°, using simple press tool for first operation.

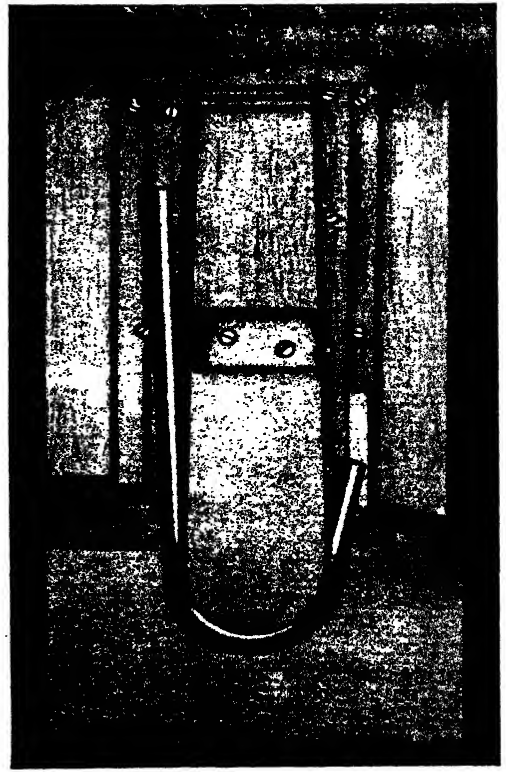


Fig. 238.—First operation completed.

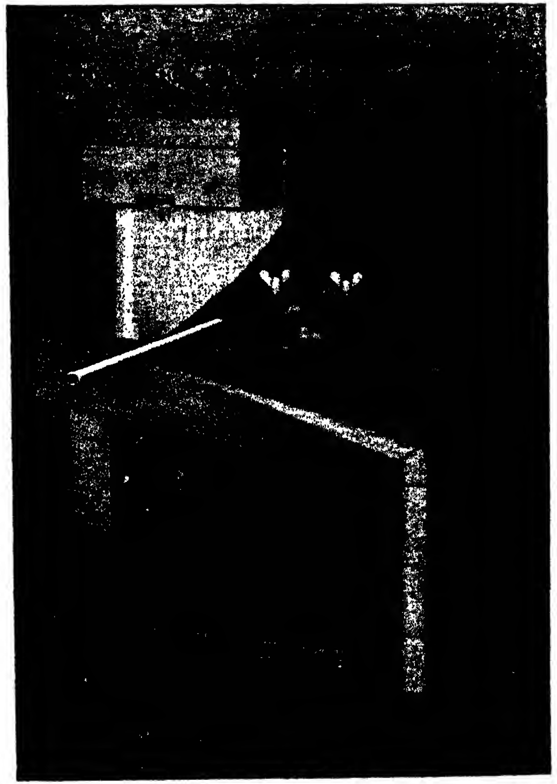


Fig. 239.—Loop bend, commencement of second operation with helical-faced tool, pipe gripped in clamps.

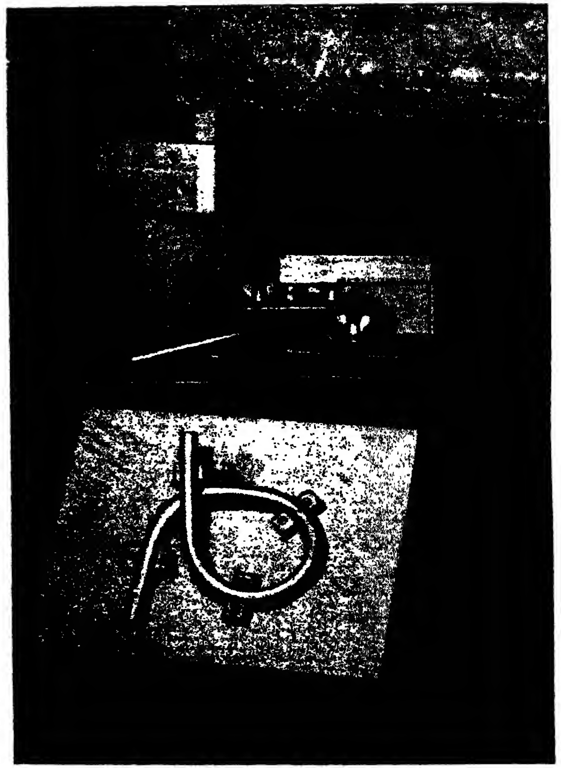


Fig. 240.—Final operation with helical tool on loop pipe. Finished part in inspection fixture in foreground.

The pipe is then removed from the first fixture, and for further operations the finished portion is held in a side extension of another fixture which locates it ready for the third set of bends. The punch having descended, it is clamped to the die in the " closed " position by two wedges as before, and again the whole fixture turned on its side. A final operation, by tools fitting into grooves in the die, is then carried out to complete the set of complex bends seen in the pipe in the lower part of the illustration.

Large Diameter Pipes

The application of the Blackburn process to the bending of a pipe of relatively large diameter is well exemplified in a further piece of double operation work. In this example the pipe is 2½ inches outside diameter, 20 gauge, and 2 feet 3 inches in

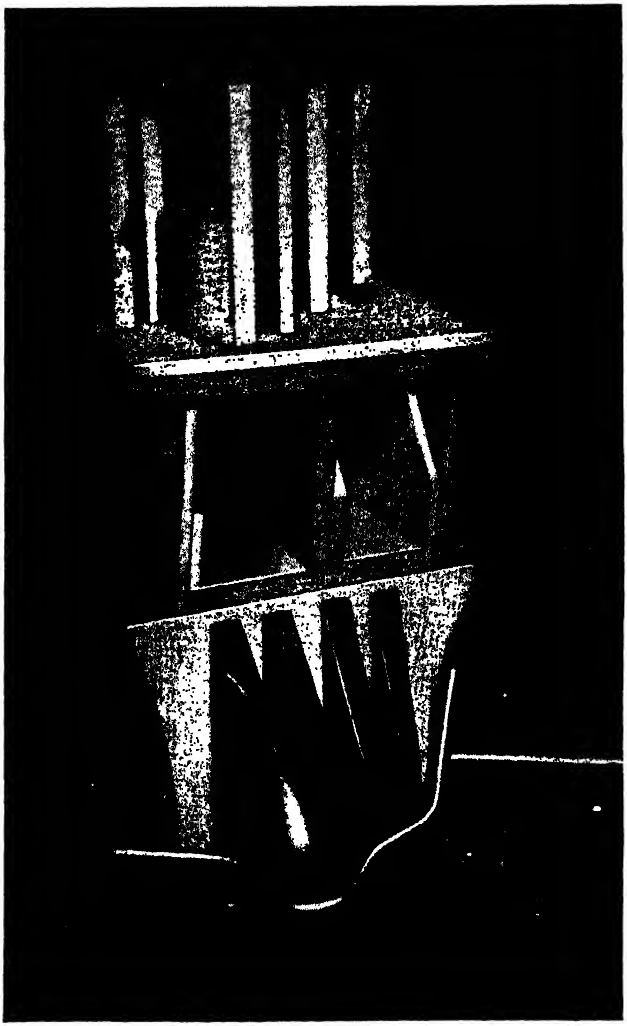


Fig. 241.—Exploded view of bending tools.

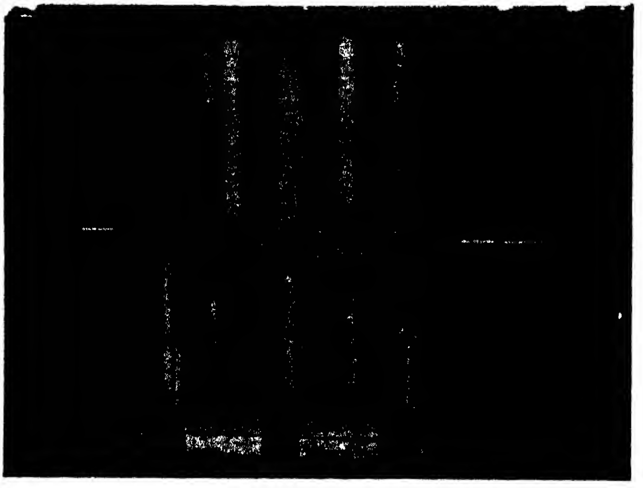


Fig. 242.—Start of bend. Pipe is ⅜ inch diam., 20g.

length, the material being Tungum. The bends are in two planes, necessitating the splitting of the work in two operations carried out in separate fixtures. Fig. 246 shows the pipe in the dies at the commencement of the first operation; to avoid side movement of the pipe it is clamped to the upper bending tool at the centre by means of a split fibre "bearing" which is held in position by means of a steel strap.

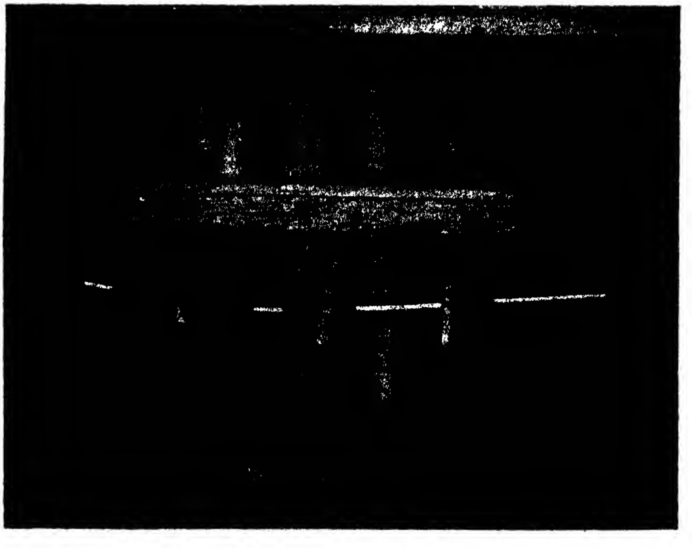


Fig. 243.—Operation half completed.

After the first operation the pipe is withdrawn from the fixture and clamped in the second die. Here it is located and clamped by two bridge clamp plates with hard-wood pads cut to form (one of which is shown removed and resting on the top of the die). The bending tool is inserted in its slide, as shown to the left of the figure, and pressed home.

The completed pipe is shown resting on the checking fixture in Fig. 251. This fixture, in addition to providing the means for checking for correct form, also provides a simple method for marking off the pipe to its correct length, by reference end plate s. The carpenter's rule gives an idea of the relative sizes of the work and tools.

Although the bends in this component are relatively simple, the saving in time as compared with handwork is very marked, the production time by the Blackburn machine method being approximately one-third of the time for hand bending. These times include all operations in the work common to the two methods, i.e., filling, emptying, cleaning, trimming, brazing on nipples, etc., for which, of course, production time does not differ.

Multiple Bending

In the design of press tools for the process various devices may be employed for increasing production and improving operation.

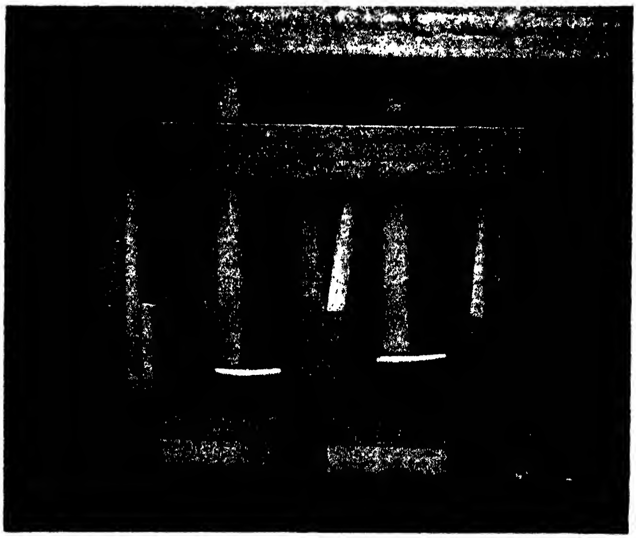


Fig. 244.—End of stroke. Bends completed.

The tools may be arranged to bend two or more pipes at a time, or to carry out two or more operations simultaneously; thus, in a two-operation job, the press may perform a first operation on one piece and a second operation on another piece which has been bent in the first operation at a previous stroke of the press. Thus, a completely bent pipe is obtained at each stroke.

Another addition to the tools of considerable help in certain cases is the provision of springs to open the dies automatically on the upstroke. Other refinements may be incorporated as the particular operations suggest.

Filling the Pipe

As in all pipe manipulation, the filling or loading of the pipes should be carefully carried out. For simple bends the filling used may be resin; one end of the pipe is fitted with a wood or lead plug, and the molten resin poured in, after which the pipe is allowed to cool before bending.

For more difficult bends, the filling recommended is " Cerrobend," a special readily-fusible alloy which possesses properties makeing it particularly suitable for use in this way. It becomes fluid at 160°F., and can therefore be made ready for use by heating in water at a temperature approaching boiling point. A hot-water tank is maintained at this temperature with the " Cerrobend " contained in a separate clean vessel submerged in the water. One end of the pipe is filled with a special wooden plug, and the filling done by ladle while the pipe is held in hot water. Since the molten filler is submerged, it will be realised that quantities of hot water will be brought up in the ladle, and this is allowed to pour into the pipe, effectively pre-heating it and preventing the formation of cold sets. The water is then displaced as filling proceeds until the pipe is fully loaded with " Cerrobend." It is then plunged quickly into a tank of cold water, plugged end downwards, so as to ensure a fine crystalline structure in the alloy and to make it ductile. The presence of scum must be avoided or faulty filling and bends may result.

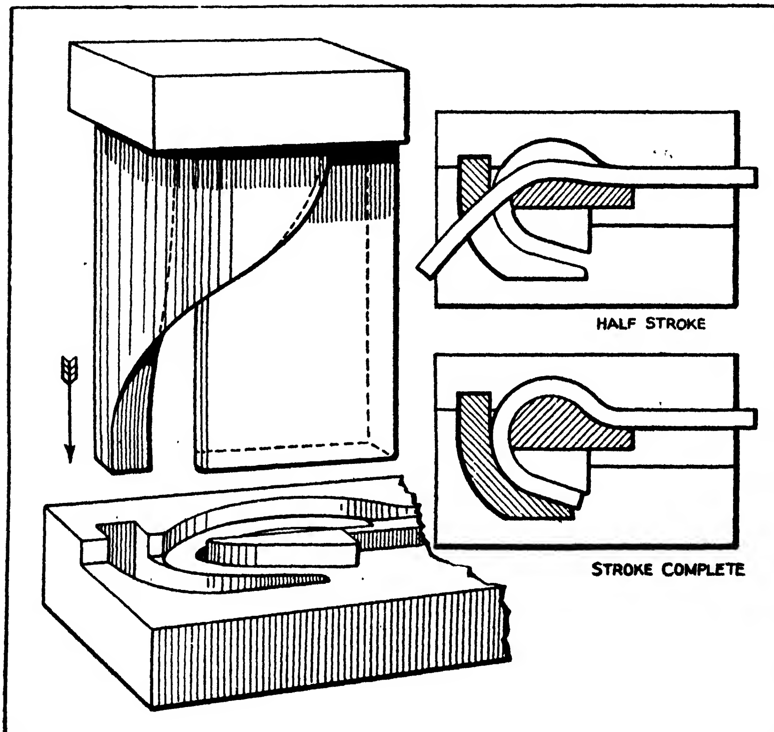


Fig. 245.—Helical-faced tools for producing hook bends.

There is little tendency for the filler to adhere to the pipe walls, but a film of oil on the pipe wall is recommended to prevent this. A mixture of engine oil and paraffin, into which the pipes may be simply dipped, is recommended. The oil film is not broken by the " Cerrobend " at the low temperature at which it is used.

The special wooden plug referred to is an oversize to the pipe, and is driven in to ensure a perfectly tight joint, as the " Cerrobend " is very searching and will find the smallest leak.

After cooling, the work must be allowed to reach room temperature before bending is commenced. Preliminary warming in a bath of warm water 160°F. prior to bending is recommended.

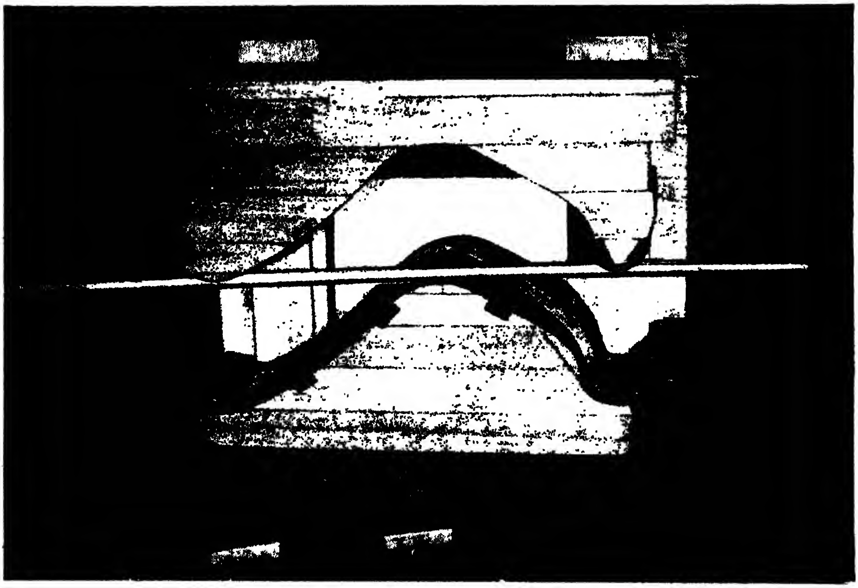


Fig. 246.—First operations on pipe 7 feet long.

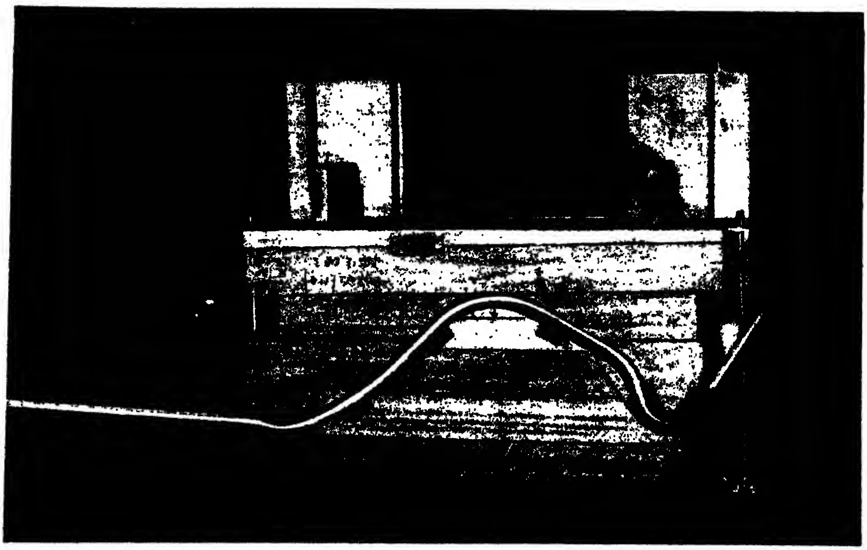


Fig. 247.—First bends completed.

Processing and Checking

After tooling up (and greasing the punch and die) the required bending operations are carried out, after which the part is checked by template which indicates the relative end positions and a number of intermediate points. One great feature of the method of bending employed is its constancy, and once the tools are correctly made the template is used principally for marking off to length and periodical checks.

Unloading the Pipe

Resin filler is removed by removing the end plug and heating the pipe evenly till the resin begins to move. It will be found to slide out in lumps, and heat is maintained until the bulk of the filler has left the pipe.

"Cerrobend" filling is removed by standing the pipe in the hot water tank until the filler has all left the pipe, which is then plunged into cold water to solidify any particle left inside, facilitating cleaning. Steam or hot air at a temperature approximating to boiling point of water is successful in removing the filling (a gas flame or torch should not be used as damage is likely to be caused to the tube walls), but it is preferred to pull through the pipe with a flexible wire brush which may be followed by a cloth. The "Cerrobend" can be used repeatedly again and again with very little wastage.

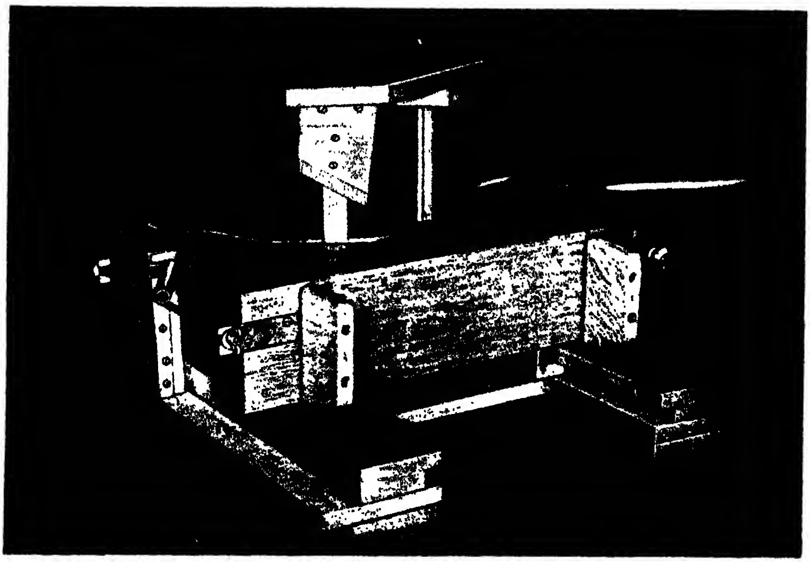


Fig. 248.—Fixture turned on its side for second operation.

Finishing off

After bending, the pipes are trimmed to length to points marked from the checking template. It is important to cut the ends square and to remove all sharp edges carefully in order to avoid starting cracks during subsequent operations. The ends are then finished as required by belling or beading, any nuts or loose rings being threaded over beforehand, of course. As with all pipe work very thorough cleansing of the pipes must be carried through. The cleaning process will vary somewhat according to the material and the equipment available. One point to note is that where loose rings or coupling nuts are of Duralumin they must not be fitted to pipes of copper or Tungum which are to be submitted to a full cleaning process as detailed in the following paragraph. Discretion must, of course, be used in arranging the sequence of operations in such cases.

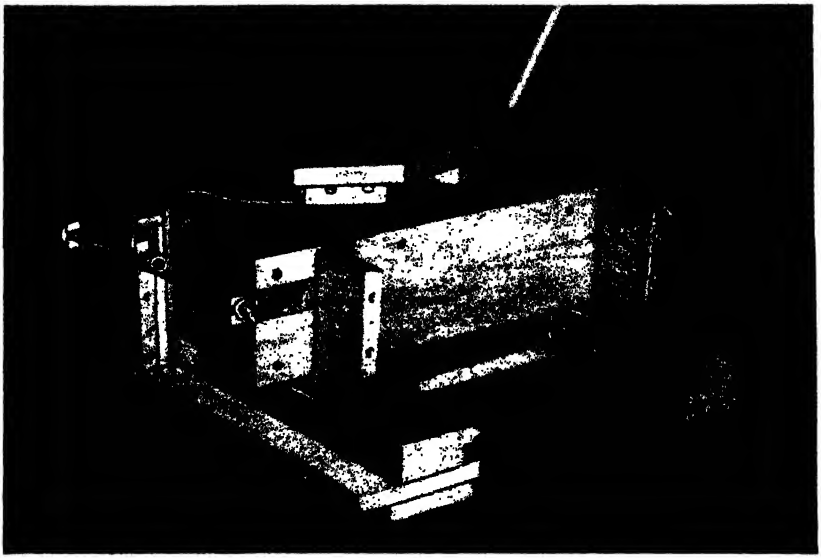


Fig. 249.—Second operation, bends completed.

Fig. 250.—Finished portion of pipe held in fixture (left). Beginning of third operation.

Cleaning

The final cleaning of pipes will vary with the material used and the equipment available. For aircraft work with Tungum and copper the treatment at present in use is as follows :—

(1) Immersion in a degreasing bath. Trichlorethylene vapour for 15 minutes.
(2) Hot-water wash—temperature near boiling point.
(3) Immersion for 1 to 5 minutes in dilute sulphuric bath, to D.T.D.901 of Nov., 1936 (Bath A).
(4) Cold-water wash.
(5) Hot-water wash—temperature near boiling point.
(6) Dry off by hot air or other approved method.
(7) Brush inside of pipe to remove any foreign matter, using special brush of brass wire.
(8) Blow air through pipe to remove dust.
(9) Seal ends.
(10) Parts are finally numbered by attaching necessary stick-on label as required.

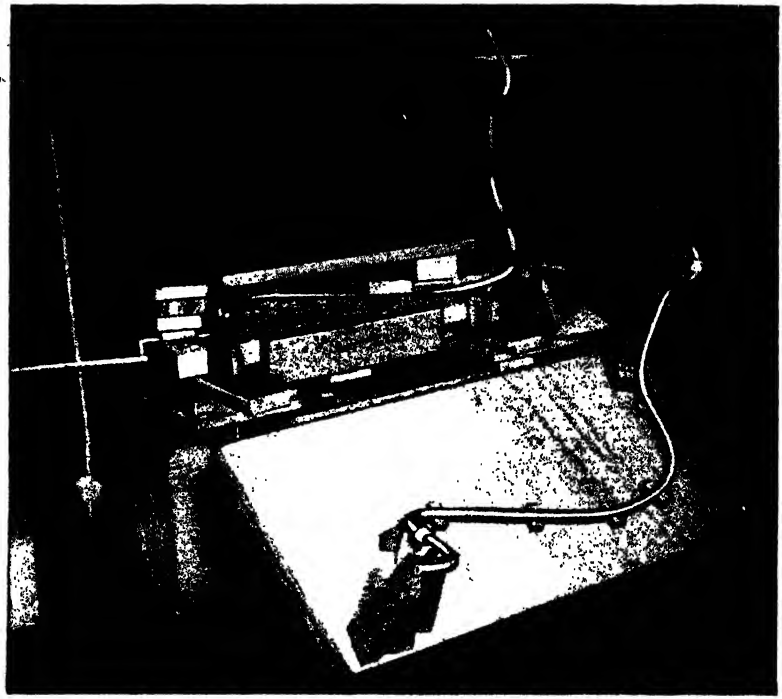


Fig. 251.—Final bends completed. Finished part on inspection fixture in foreground.

For Duralumin pipes Stage 3 in the sequence above is definitely omitted

Pipes of aluminium are cleaned after working by similar processes to those for Duralumin.

Suitable inspection operations are, of course, included to cover the process, attention being given particularly to the checking fixture, freedom from sharp edges on the ends and cleanliness of the pipes.

Effect on Wall Thickness

Some queries have naturally been raised as to the possible effect of the bending process on the thickness of the pipe walls. As with all other methods of bending a

reduction of thickness was to be expected on the outer radii, and a similar increase in wall thickness on the inner radii. Extensive tests have been carried out by sectioning a series of pipes after bending to ascertain whether this effect was in any way excessive, but the results prove that the process is eminently satisfactory in this respect. The following Table gives a typical series of test results from which it will be seen that the variation in wall thickness is well within the limits allowable, the variation being in some cases only of the order of .002 inch. The material is Tungum.

Diameter	Radius of Bend	Inner Wall	Outer Wall	Nominal Wall Thickness
1″	3½″	.03″	.027″	.028″
1″	3½″	.031″	.025″	.028″
¾″	3⅜″	.032″	.026″	.028″
¾″	3⅜″	.03″	.026″	.028″
¾″	1⅝″	.034″	.025″	.029″

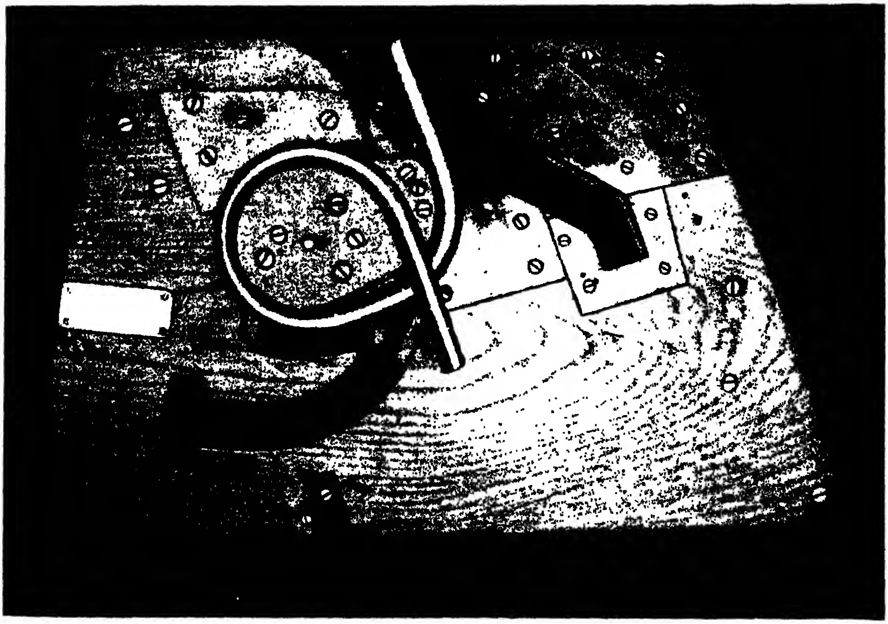


Fig. 252.—Fixture for second and third operations on loop bend.

Production Times

A selection of production times for typical aircraft components with comparative figures for handwork, is given below as a rough indication of the savings possible by the Blackburn process. It should be noted that in many instances the work of preparing and finishing constitutes a large proportion of the total man-hours, but in spite of this production times are in nearly every case reduced to a mere fraction of the times for hand methods.

Material	Dimensions of Pipe	Time taken by Hand		Time taken by Press	
		Hrs.	Mins.	Hrs.	Mins.
Copper	¾″ o/d × 20*g* × 1′ 6″ long	3	15	–	33
Tungum	⅝″ o/d × 22*g* × 5′ 0″ long	9	00	2	33
Tungum	1″ o/d × 22*g* × 8′ 6″ long	9	00	3	00
Tungum	¾″ o/d × 22*g* × 8′ 6″ long	7	00	2	45
Tungum	⅝″ o/d × 24*g* × 4′ 6″ long	2	25	–	38
Tungum	1½″ o/d × 22*g* × 3′ 8″ long	5	30	–	58
Tungum	¾″ o/d × 24*g* × 2′ 9″ long	4	15	–	56
Tungum	1″ o/d × 22*g* × 3′ 9″ long	4	35	–	48
Aluminium Alloy ..	½″ o/d × 24*g* × 6′ 0″ long	2	00	1	02
Aluminium Alloy ..	½″ o/d × 24*g* × 5′ 0″ long	2	00	–	54

NOTE—The Blackburn Fipe Bending Process and special tools are protected by British Letters Patent No. 543,362 and other British and foreign pending patent applications.

RIVETING

CHOBERT RIVETING

Riveting from one side only

IN the construction of aircraft the introduction of metal has materially increased the time required to cover an airframe, one of the principal reasons being the relative difficulty of joining together metal as compared with wood and fabric. Whatever its shortcomings, the method at present accepted of making joints and seams in metal is by riveting. which, from the aircraft designer's point of view, has the essential advantage of enabling him to determine accurately the strength of all his joints.

Riveting is of necessity a lengthy operation, and when applied to metal aircraft is very largely performed by hand. Anything which, at this period of expansion, tends to reduce the time required to construct an aeroplane merits careful consideration. A step in this direction is the automatic, hand-operated Chobert riveter. With this tool, access to only one side of the work is required to complete the riveting operation; it is therefore specially suitable for such components as wings and tail units, in which access to the under or inner side is most difficult.

Type of Rivet

The rivet employed for this system is of the tubular type and has an internal lip or restriction at the end opposite to the rivet head. When a cone-shaped mandrel is drawn through the rivet it forces the restricted portion outwards to form a shoulder or flange which bears on the underside of the sheet to be riveted. Alternatives to this system are: (1) To use a mandrel which is deformable, the conical end of which, after forcing out the end of the rivet, then proceeds to squeeze itself small enough to pass through the rivet. (2) To use a mandrel having a weakened neck and breaking at a predetermined load. In both the above cases a fresh mandrel is needed for each rivet. (3) A German system in which the rivet has a closed end and is expanded by means of a special tool in stages. (4) A French method which makes use of a spinning tool to turn over the inner end of a tubular rivet, the bore of which has to be large enough to admit the goose-neck of the spinning tool.

Certain limitations of the foregoing have been overcome by the Chobert system in that not only can the same mandrel be used indefinitely, but it is made to serve as a magazine on which a number of rivets are threaded.

The strength of each rivet is constant, as the deformation of the internal restriction depends only on the difference in diameter between the interior of the rivet and the mandrel head, which is controlled within very fine limits.

Rivets as small in diameter as ⅛ inch and of practically any metal can be used. Work can be carried out on unsupported sheets as the reaction necessary to "upset" a rivet takes place between the nose of the tool and the head of the mandrel.

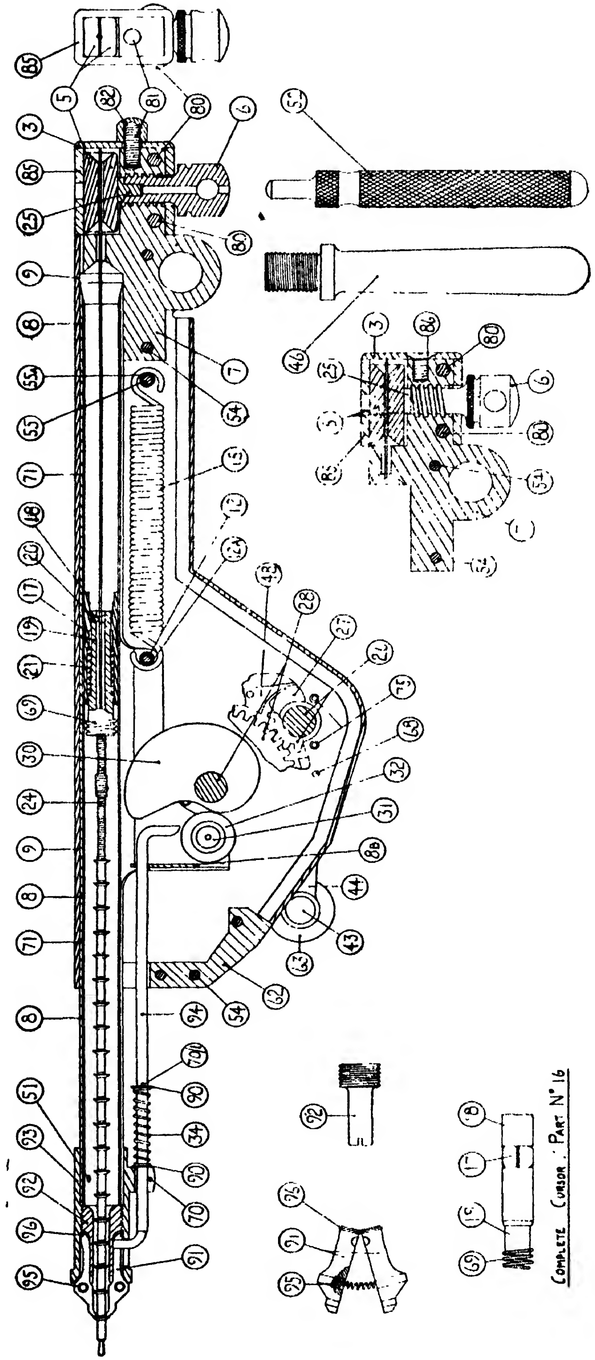


Fig. 253.—Chobert Riveting Gun.

Action of Chobert Gun

The action of the Chobert riveter or gun can be seen from the sectional view in which the long mandrel threaded with rivets is shown. The tail end is secured by means of chuck jaws in the " stock " of the gun. Upon turning the cranked handle in a clockwise direction, the cam, through the interposition of a 3 to 1 gear, is rotated in the opposite direction, forcing the " barrel " of the gun forward, and with it the first rivet over the enlarged end of the mandrel, the return being effected by means of a strong spring.

It will thus be seen that in operation the mandrel is stationary and the barrel moves forwards and backwards, the relative movement of the " muzzle " over the mandrel end being made to perform the riveting operation and also to feed the next rivet forward into position.

When the barrel of the gun is in the fully retracted position, the first rivet is ready for insertion into the hole previously drilled for it. The opening of the two-jaw chuck in the muzzle of the gun to allow the passage of the second rivet does not take place until one turn of the handle has been completed, i.e., until the first rivet has been broached.

This mechanism is simple in operation, and consists of a conical seat formed in the open end of the muzzle to accommodate the halves of the split chuck. These halves enclose a tube which serves as a guide to the issuing rivets, the whole being

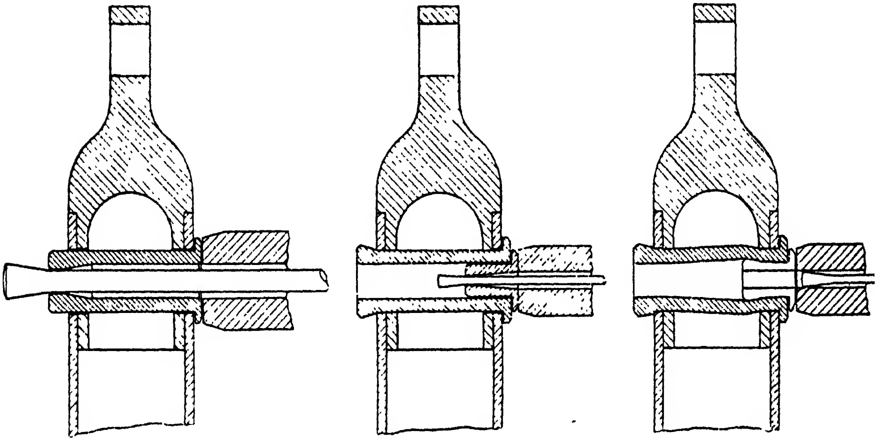


Fig. 254.—Three stages in riveting a tube with Chobert rivets.

encircled with a " circlip " spring. This spring serves to hold the assembly together, to open the half-jaws when relieved from their conical seat.

After the cam passes the position of maximum lift the barrel is retracted, but the return of the control fork, and with it the two-jaw chuck, is delayed through still being in contact with the cam. The issue of the next rivet is thus permitted and thereafter the jaws close behind it, and the gun is ready to repeat the performance.

The rivets are fed forward along the rivet pin or mandrel shank by an ingenious adaptation of a well-known principle. The free-wheel slide or cursor is a sliding fit in the barrel, and is free to be carried forward by the barrel, but is restrained on its return by the balls engaging the mandrel.

The gun can be quickly reloaded with a second mandrel previously charged with rivets after slacking the square-headed screw operating the chuck-jaws in the stock of the gun and setting the two-jaw chuck in the muzzle in the open position.

Speed of Operation

Speed of operation is a matter of experience, but with little practice even an unskilled operator can, on straightforward work, place 1,200 rivets per hour. Rivets of various

lengths and diameters in different materials can be placed; the change of diameter however, requires a change of mandrel and chuck. Rivets are made up with either snap heads or counter-sunk for flush riveting, and where additional strength of water-tightness is required, sealing pins are used to plug the rivets.

Taper bore rivets have been developed for the system, and it has been found that by suitably proportioning the taper relative to the length of the rivet and the head of the mandrel, a tolerance of plus or minus 0.032 inch in sheet thickness is permissible as against plus or minus 0.004 inch with the stepped type of rivet. Furthermore, the rivet is stronger, and holes oversize by as much as 0.010 inch can be filled.

For placing odd rivets in inaccessible corners the " A " or single shot gun is used which can be fitted with a right-angled or flexible extension.

The Chobert system, handled in this country by Aviation Developments, Ltd., is used by the Air Ministry for repairs to metal aircraft in the R.A.F. In this field the equipment has the additional advantage of being light and portable.

Locating Sheets

For use with this and other systems of riveting a little tool for locating and drawing together sheets of metal as a preliminary to riveting has been developed by the company's chairman, Sir Alliot Verdon-Roe.

The A.V.R. patent sheet gripper is simple in operation, and consists of a screwed claw which, after engaging the undersheet, withdraws into the knurled head. The base plate of the tool is formed with a spigot of the same diameter as the hole which serves to locate the sheets as they are drawn together. It is made in sizes suitable for holes from 3/32 inch in diameter upwards.

Extended use of Taper Bore Rivet

A difficulty met with in the practical application of this riveting system as originally developed in France was the necessity for maintaining close tolerances on both the stepped type of rivet employed and the thickness of the sheets. This tolerance was of the order of 0.032 inch and represented a condition practically incapable of realisation under working conditions. Even neglecting the inevitable variations resulting from the rolling of the sheets, a slight wave or bend, quite insufficient to render the metal unusable, would easily result in such a tolerance being exceeded. One of the most important of the more recent developments in connection with the Chobert system is the extended use of the taper bore rivet. This permits wide tolerances of the order of plus or minus 0.032 inch in material thicknesses to be riveted and makes possible the use of unskilled labour in performing the operation. It is also possible to expand these rivets up to 0.010 inch oversize, so compensating to some degree for inaccuracies in drilling. The broaching action of the mandrel definitely expands the rivet to fill irregular and oversize holes and, in addition, produces sufficient tail to give ample " tear-out " values.

The operation of closing the rivet not only makes a tight joint, but in doing so leaves a parallel bore of known diameter. This parallel bore enables the rivet to be converted into what is for all practical purposes one of a solid type, since a pin, say, 0.0015 inch larger than the diameter of the bore can be driven in and will remain tight. This additional operation is only necessary for exposed positions or those few cases where extra strength is required.

Riveting Tubular Members

Among several special rivets incorporating the Chobert patent taper bore, one used for pinning sockets or shackles to tubular members, is of particular interest. The problem when placing all long rivets and pins is to avoid bending or buckling of the stem.

The principle made use of by this system is such that end pressure is not required for the purpose of head formation. Consequently, frail box or tubular sections are readily cross-pinned or riveted without buckling or without fear of distortion to either work or rivet.

The taper bore at the tail end of the primary rivet causes this end to be expanded into the tubular member and socket. To expand and fix the head end of the rivet a secondary rivet with taper bore is placed in the bore of the primary rivet. When

this is expanded it swells both primary and secondary rivet into the tubular member and socket, securely pinning this union.

Improvements have also been made in the riveting guns, both automatic feed and single action type, to improve further their reliability and convenience of operation. A simplification in jaw control and strengthening of the jaws now permit the automatic feed gun to place all alloy or steel rivets from $\frac{1}{8}$ inch to $\frac{1}{4}$ inch diameter and up to $\frac{1}{2}$ inch in length. Single-acting guns can place rivets of larger diameter and lengths.

An interesting development in single-acting guns is a range of straight and angular extensions which permit of " remote " control, for placing rivets inside cavities and box sections or under brackets. Locations almost inaccessible by other means can be reached in this way and rivets securely placed.

Riveting guns for placing these rivets now available are as follows :

" R " type gun is a preloaded repeat acting gun where continuous or long run riveting has to be carried out. With this gun not only is the placing of Chobert rivets effective but it is easy enough in application for girl labour to be used, and is so fast that riveting speeds of 800 1,000 rivets per hour is readily possible.

" B " type gun is a heavy duty preloaded repeat acting gun for placing the larger diameter and longer length rivets. It is slower in speed than the " R " type but still permits high rates of production with ease of operation to enable girl labour to operate it. Mostly used for the larger diameter and longer length of steel rivets.

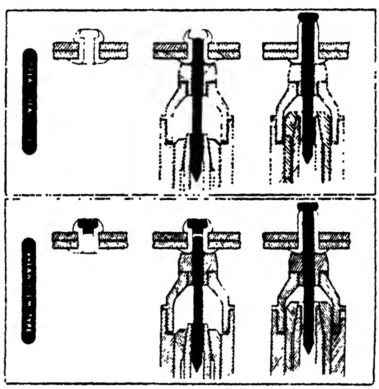


Fig. 255.—Riveting with " Pop " rivets of the break-head type (above) and break-stem type (below).

The " A " type gun is a single acting gun in which each rivet is individually placed. The production rate with this gun is slower. With this gun can be supplied a range of extensions straight or curved, for reaching into inaccessible places such as box structures and under trunion arms, and whilst it is much slower in riveting speeds than the repeat acting gun, the " A " gun is really a necessity for modern aircraft production.

Chobert rivets can be supplied in shank dimensions of $\frac{1}{8}$ inch, $\frac{5}{32}$ inch, $\frac{3}{16}$ inch $\frac{1}{4}$ inch and $\frac{5}{16}$ inch and in lengths ranging up to $\frac{5}{16}$ inch, in the case of the $\frac{1}{8}$ inch to, $1\frac{1}{2}$ inch in the case of the $\frac{5}{16}$ inch. In addition to the above, which can be considered as standard sizes, many special rivets have been developed where extra strength or extra length is required as may be necessary for, say, shear bushes, steel ferrules and cross-pinning applications. Available materials include Dural L.37, Non-heat-treatment aluminium Alloys N.A.16S.T. (D.T.D.327) and M.G.5 (D.T.D.303) and also steel or brass.

TUCKER HOLLOW RIVETS

THE many advantages of Tucker hollow rivets for metal constructions are to-day recognised by leading aircraft designers, works managers, production managers, etc. Tucker hollow rivets of the "Pop" type are very largely used in the construction of modern British aircraft. At one time designers of the metal framework laboured under the severe handicap of having to plan their designs so that in the actual building of structures both ends of all rivets were accessible. The introduction of the "pop" rivet eliminated this trouble as it enabled the blind or one-sided riveting process to be adopted, and consequently permitted important improvements to be made in the design of metal construction for aircraft.

"Pop" Riveting

As already mentioned, the introduction of "Pop" rivetin gwas an extremely important and valuable development in the construction of metal aircraft. As a blind riveting process, the setting or clinching of rivets was made possible in hitherto inaccessible positions. Fuselage, hulls, wings, bomb girders, undercarriages, engine nacelles, floors, etc., were considerably simplified in design, and construction and assembly work was greatly speeded up. Whilst "Pop" rivets were therefore originally intended for blind or one-sided riveting, they are also extensively used for general riveting work in place of solid rivets.

Fig. 256.—Two types of portable riveting tools for "Pop" rivets.

"Pop" rivets in nickel alloy are equal in strength to solid rivets in aluminium alloy of the same diameter, they can be set at a greater speed and unskilled labour can very quickly be taught to operate any of the wide variety of special portable setting tools.

"Pop" rivets are tubular in form. They are produced from sheet pressings in a number of alternative metals to suit the requirements of aircraft designers. In the main they are made in nickel alloy or aluminium alloy, and to a lesser extent in mild steel. "Pop" rivets are made with flat, domed and countersunk heads. The rivet itself is a cup-shaped pressing having a hole in the end through which a mandrel is threaded. Mandrels are supplied in hard steel and are available in three types.

The setting operation for "Pop" rivets is carried out by portable tools supplied for this purpose. The mandrel with rivet is inserted into the tool, so that the rivet head rests against the anvil. The rivet protruding from the setting tool is pushed into the

pre-drilled hole in the members to be riveted, and the tool is then operated, applying tractive force to the mandrel. The operating part of the tool is so designed that pressure is exerted upon the rivet in the direction in which it is pushed into the hole, and at the same time the mandrel, held by the collet, is pulled in the reverse direction. The latter operation causes the mandrel head to come in contact with the projecting end of the rivet and this shortens and thickens it throughout. This action swells the rivet to fit the hole and at the same time draws the plates together—actually, the nominal diameters are increased by as much as .060 to 0.80 inch.

It will be seen that even if the hole is oversize, this comparatively large expansion of the shank of the rivet gives a tight joint and absolute security. Tight riveting and large heads are essential in modern aircraft construction, and these are two outstanding features of "Pop" rivets, which enable their full strength to be developed in tension as well as in shear. In the setting operations, the rivet first collapses under the compressive load and immediately this happens the whole load is taken by the laminations being riveted, causing them to be pulled tightly together. At the same time the rivet head continues to form until the joint is solid, a condition which must occur before the mandrel breaks. The riveting force, which compresses or squeezes the rivet and joint solid, varies from 600 lbs. to 1,600 lbs., according to the size of the rivet.

"Pop" riveting requires only one operator. It does not require another to hold up. The simplicity, efficiency and reliability of the "Pop" riveting process has made it popular for overcoming limitations of inaccessibility, such as when connecting fittings to tubular members, etc., because of greater setting speed and less expensive equipment, also "Pop" rivets are now preferred to solid rivets, even for structures where both ends of the rivets are accessible.

Break Head Type

The break-head mandrel has a flat or cheese type head so that the rivet is set as though it was snapped between two sets like the usual method of setting solid rivets. The point of breaking is immediately beneath the head, hence its description. After setting the rivet, the mandrel head breaks at the designed load and drops away when the rivet is not projecting excessively through the plates. All mandrels are pointed to facilitate rapid insertion in the setting tool.

Break Stem Type

The only difference between the break-stem type of mandrel and the break-head described above is that the point of breaking is .05 inch from the head. Another important feature of this type of mandrel is that the head is oval, and on this account the head of the broken mandrel is retained in the "snapped-up" head of the rivet. This type is used where it is required to seal the rivet or where there is no outlet inesid the structure for the broken-off head of the mandrel.

SELF-ADHESIVE TAPES

Self-adhesive tapes, of the types made by Industrial Tapes Limited, are used in colourless form to protect metal ribs and spars from the corrosive effect of the solvents in the doped fabric which covers the wings. The metal is covered with a wide strip of self-adhesive which presents a smooth surface to the fabric as well as protecting the metal.

Another use in aircraft production obviates a minor source of delay in riveting—the attention necessary to loose or dislodged rivets preplaced in position : the mechanic who precedes the riveter not only insets the rivets in their holes, but covers them with a strip of self-adhesive tape, which permits the riveter to work considerably faster.

These tapes can also be used for the protection of sensitive surfaces during manufacturing operations, the masking of parts during spraying, sealing pipe ends, and the insulation of electrical wires and cables, as during coil winding. Tapes for these purposes need not be transparent, and consist of adhesive fabric.

Coloured tapes, in various widths and combinations, are used for the identification of cable runs.

Identification Tapes

Lassolastic Identification Tapes, produced by Herts Pharmaceuticals, Limited, take the form of thin self-adhesive markers which adhere instantly to any drv surface

by firm pressure. They offer no undesirable thickening at point of contact and create no obstruction to coupling units or other appurtances on pipes or conduits ; and can be affixed anywhere without necessitating disconnection.

The identifications, which cannot be erased, take the form of any desired style of printing and colouring; are spaced at regular intervals to suit individual requirements ; and may be procured in a range of widths, dictated by the amount of lettering in the designation.

Lassolastic is completely waterproof; highly resistant to fluids and heat ; and remains permanent, distinctive, and always legible.

MOBILE ASSEMBLY METHODS

THE advent of the cantilever monoplane with its high performance and increased wing loading, leading to much greater imposed stresses and greater weights, had the effect of compelling manufacturers to use rather more substantial equipment for supporting their aircraft and components during assembly.

Various manufacturers in various countries tackled this problem. In Germany the Junkers Company has taken out a number of patents covering some extremely interesting ideas, mainly in connection with jigs, but in at least one case with a combination of jig and assembly trolley for manufacturing fuselage components and assembling them to each other.

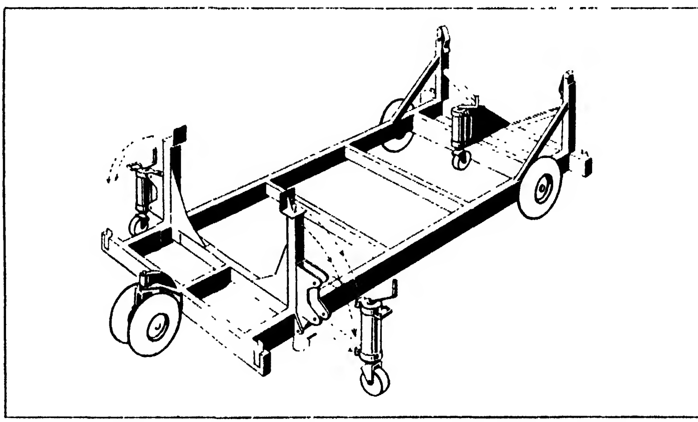


Fig. 257.—A typical Esavian assembly trolley for supporting a fuselage section. It is equipped with tyred wheels and wheeled jacks, but these are not used simultaneously.

A further interesting Junkers idea is a form of flying jig, in which jig ends for a centre section, for example, are given an aerofoil shape and adapted to be built into the wings of an aircraft as an additional section to enable them to be flown to the scene of a crash for carrying out an emergency repair. The idea is ingenious, but appears to have considerable disadvantages when compared with shipping such parts in a transport aircraft in the ordinary way.

In the main, however, the tendency of most manufacturers was towards the use of more and larger overhead runways, in connection with trestles similar to those previously employed.

The period from 1936 to the present date has seen a rapid and progressive increase in the rate of airframe production. This increase has involved the construction of many new factories, and, more important from the handling point of view, the pressing into service of many existing buildings not designed for aircraft construction. In addition, it has entailed a vast extension of the system of sub-contracting applied to completed sections of aircraft. During this period, also, the trend in design has been ever more towards sectionalising aircraft for construction as complete components on these lines.

A fair example of the method is the case of a bomber type, whose three main fuselage sections are constructed in Leicestershire, Warwickshire and Staffordshire, the centre section in Cheshire, outer wings and tailplane near London, the complete aircraft being assembled in the West of England. Each section of the aircraft arrives at the assembly plant in a finished state, with flying controls, wiring and hydraulics, installed and ready for connecting up. The weights of the sections range up to five tons, or even more. In order to make full use of the advantages of the dispersal and sub-contracting systems it is essential that the assembly methods should be rapid, ensuring a smooth flow of finished aircraft to the flight shed without large extensions to the assembly floor area. At the same time the maximum economy of assembly labour must be secured.

Under the new conditions it was generally found that the old methods of handling, support and transportation were inadequate, in some instances even dangerous. They were also wasteful of manpower, which in many cases was reduced to womanpower, and was becoming scarce at that.

Simultaneously, with the outbreak of war the work of the aircraft repair and maintenance organisations, service and civilian, became very much increased. The personnel of service maintenance units was expanded manifold, and the need for more and better equipment was inevitable. On the civilian side, under the direction of the Civilian Repair Organisation, nearly all the civil airport and airline maintenance shops, in addition to a multitude of firms from railway companies to garages, who had little previous experience of aircraft, were recruited for repair work.

At about this time Esavian, Ltd., began to interest itself in aircraft handling problems. Nearly every manufacturer was too fully engaged on the production of existing types, or more particularly the tooling up of new ones, to be willing to burden his tool drawing

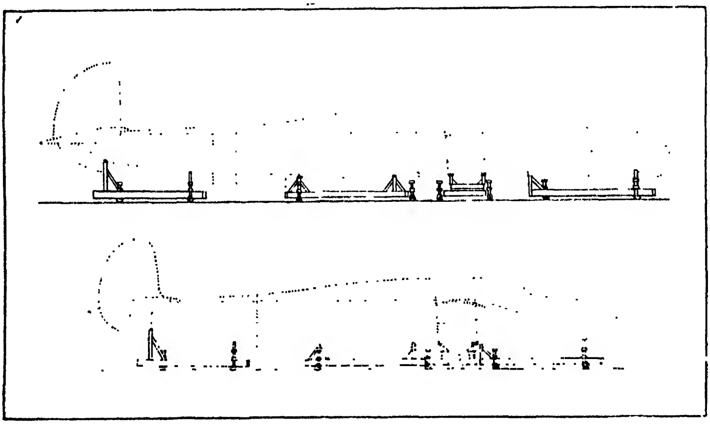


Fig. 258.—Trolleys applied to the assembly of a twin-engined medium-bomber type of aircraft. The bottom diagram shows the sections immediately after they have been bolted together.

office and maintenance shop with the design and manufacture of large quantities of shop equipment. Some who had tried were only too glad, after a certain amount of bitter experience, to find a specialist firm who could undertake this work.

Development

When specialisation in the field of handling equipment came into being the existing methods came under the review of fresh minds. From a new viewpoint unhampered by traditional methods, it was possible to visualise new methods. This outlook extended also to the ancillary handling requirements connected with repair, transport, storage and salvage.

The essential characteristics of the equipment were dictated by the demands of the Services for aircraft in the largest possible numbers in the shortest possible time, and by the existing organisation of the airframe and engine manufacturers. In its design

many of the best features of existing equipment were incorporated where applicable, whilst in all cases the greatest attention was given to mobility, having regard to the type of floors or ground to be traversed. Arrangements for jacking were included where this was required, and for transferring the load to and from the equipment in all cases.

Typical Problems

Examples of the handling of various aircraft are described below to illustrate some of the methods now being adopted. It will be understood that it is not at present possible for security reasons to mention the names of all the aircraft types or to publish accurate outlines of the machines.

The first example falls into this category. It is a twin-engined aircraft of medium weight and fairly conventional design, except that it was designed with a view to manufacture in components on a widely dispersed basis. Each component is completed in all possible detail before shipment to the main assembly plant. The aircraft has a tubular frame, with plywood and light-alloy skin panels. The main components to be dealt with are—front fuselage, wing centre section, centre fuselage, rear fuselage, outer wings, and tailplane.

Mobile Cradles

For the fuselage components, the method adopted was to provide suitable cradles to support the bottom tubular longerons at four points.

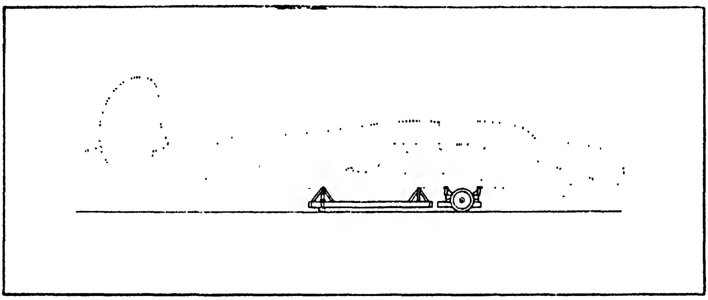


Fig. 259.—After the second stage shown in Fig. 258, the nose- and rear-section cradles are removed and the aircraft is supported on the rear jacks of the centre fuselage trolley and the tyred wheels fitted to the wing centre section trolley.

These cradles were adapted to receive detachable jacks with caster-wheeled feet and sets of steerable pneumatic wheels. The cradles, or frames, are distributed between the main assembly factory and the various sub-contractors, each sub-contractor having in addition a few sets of wheels and jacks.

When at the sub-contract works the fuselage frame is completed and removed from the rigid assembly fixture it is slung or manhandled—the weight at this stage being comparatively low—on to the cradle, to which the steerable wheels have been fitted. The cradle then serves as a mobile workstand for all subsequent operations in the sub-contract factory, and may be provided with hingeing of the front posts with a removable jack in the centre to enable the nose skin to be fitted.

On completion in the sub-contract works, the component is taken, still on the wheeled cradle, to the loading dock, where the component and cradle are slung on to a lorry by means of slinging points provided on the cradle. The wheels are then removed and the cradle, which secures the component by clamps, suitably lashed down to the lorry.

On arrival at the assembly factory, the component and its cradle are slung off the lorry, fitted with the wheels already described, and wheeled to the assembly floor or to storage. At the assembly stage the caster-wheeled jacks are fitted and the pneumatic wheels removed for use elsewhere. First, the wing centre section is placed in position in its cradle, then the centre fuselage, front fuselage, and finally the rear fuselage are coupled up, each component being attached to its neighbour by four pins.

After the main fuselage components have been coupled up, large-diameter wheels are fitted to the centre-section cradle at a point slightly forward of the centre of gravity of the aircraft, and the nose and rear fuselage cradles, with the forward jacks of the

centre fuselage, are removed. In this way, the aircraft is made more easily mobile on the four main wheels, which are on a common axis, with the caster jacks of the centre-fuselage cradle serving as outriggers. This method is to be preferred to any attempt to move an aircraft on a multiplicity of casters.

The aircraft is thus capable of being moved progressively down the assembly line for the completion of subsequent operations until the stage is reached where, after fitting tailplanes, outer wings, engines, and undercarriages, it may be jacked up from the normal jacking points, the undercarriage tested and finally extended, and all the cradles removed for despatch back to sub-contractors.

It will be noted that a component is supported on the same cradle from the time the frame leaves the assembly fixture at the sub-contract works until it is assembled into the aircraft at a point perhaps 200 miles distant. At all intermediate stages it has been fully mobile. The saving in manpower and the reduction in transit damage may well be imagined.

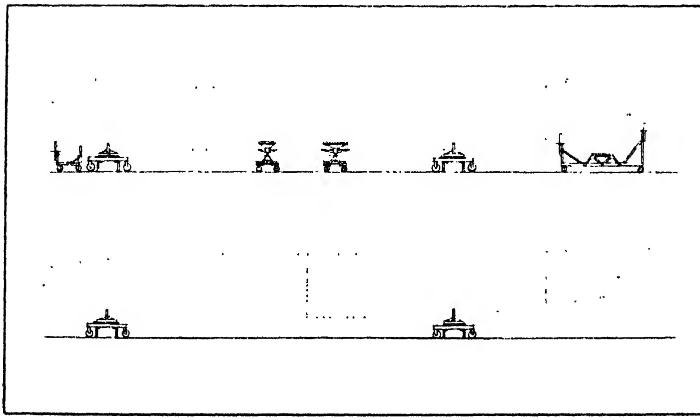


Fig. 260.—Application of the trolley system to the assembly of the Stirling fuselage.

The Short Stirling

On account of its great weight and bulk, the Stirling aircraft presents a number of interesting handling problems, both for the factory and the maintenance unit.

The main components of the aircraft are as follows :—

	Weight.
Nose portion	500 lbs.
Front fuselage	2 tons.
Centre fuselage	2 tons.
Rear fuselage	1 ton.
Wings and Undercarriage	4½ tons each.
Tail plane. Fin. Rudder, etc.	

In the assembly factory the four fuselage components, after completion of jigging operations, are handled in caster-wheeled trucks provided with jacks to facilitate the assembly of the components into the complete fuselage. Nose and rear portions are each handled in a single four-wheeled truck whilst the heavier front and centre fuselage components are each handled on two trucks. At the outer end the trucks are of heavier construction, so that when the whole fuselage has been bolted together all trucks but these two may be removed. It will be appreciated that there is some difficulty in manœuvring a large and heavy fuselage in a multiplicity of trolleys, especially as in some cases the levelling of the floor leaves a good deal to be desired.

Such loads as those quoted are beyond the capacity of ordinary commercial casters. It was, therefore, necessary to develop a series of casters of heavy construction with large-diameter wheels and generous offset for loads of one ton and upwards each.

Wing Handling

The handling of Stirling wings is an especially interesting problem, both from the manufacturing and maintenance points of view. These wings are of especially large size, about 47 feet long and weighing, with undercarriage, about 4½ tons.

Naturally there are many operations to be carried out on the wing after it has been removed from the fixture before it is ready for assembly to the aircraft. It is the practice to carry out this work on trestles, each composed of a beam and two tripods provided with jacks for levelling. The beams are adapted to fit on the jacking heads of a four-wheeled steerable truck, which is run into position between the tripods when the wing is ready for removal from the assembly fixture. It is worthy of note that this large wing is moved in a shop with a bare 15 feet of headroom and a very light roof-structure incapable of supporting any crane gear. The wings can be moved with ease by a Lister or Douglas or similar type of truck.

This system of wing handling offers special advantages from the maintenance point of view. In the case of " on site " repairs it frequently happens that the main operation is to change one wing, as for example in the case of damage to the wing in landing or by enemy action. The procedure, using a truck generally similar to that described above, is as follows :

> After fully retracting the undercarriage and removing the leading edge tanks the aircraft is lowered almost to ground level by means of special high-lift jacks engaging the fuselage immediately forward of the front spars. After supporting the undamaged wing by means of a trestle, the wing truck, again with extended

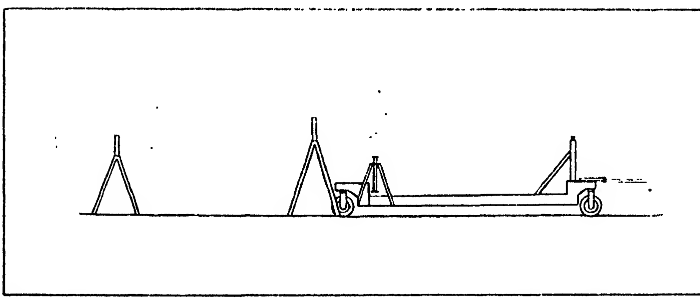


Fig. 261.—Diagram showing the method of removing a Stirling main plane from its assembly fixture.

> detachable beams, is positioned under the damaged wing and the weight taken up on the jacks. The wing attachment bolts are then removed, the wing withdrawn from the aircraft and run to a suitable position for loading to a low-loader lorry.
>
> Loading is done by raising the wing truck jacks to their fullest extent and then placing suitable tripods under the detachable supporting beams which are extended sideways sufficiently to allow a low loader to back in between the tripods. Once the beams have been raised by the tripod jacks clear of the truck, the truck may be removed, the low-loader backed into position, and the wing lowered to transport height. The inboard beam is used for transportation, being supported on suitable trestles on the sides of the low-loader, whilst the outboard beam remains at the station, support for the wing being arranged outboard of the outer engine.

The whole operation may be carried out on any reasonably hard surface. The operation of fitting a new wing is, of course, similar to that described above, but in the reverse order.

On arrival at the repair factory the wings may be transferred back to a similar truck to that just described to enable it to be taken into the repair shop, where it is set up on tripods for repair, still using the same beams. Alternatively, if it is desired to store the wings, this is done by slinging them off the low-loaders by means of shackle points provided in the top surface, after attaching special frames to the engine mountings. These frames are designed to be attached to special low-framed trucks, and to provide a hingeing point for turning the wing into a vertical position. The turning is carried out under a gantry, and the wing is then wheeled into the storage hangar, where in its vertical position it occupies but a fraction of the space it would take up if horizontal.

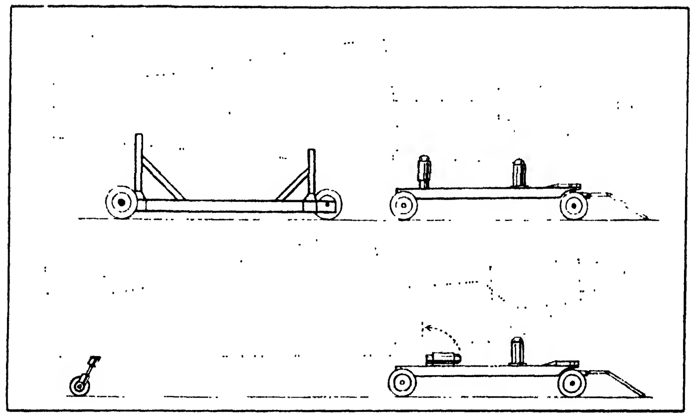


Fig. 262.—*The trolley system applied to the assembly of a single-engined fighter aircraft. in the lower view, the front fuselage is shown adapted for road transport, the rear fuselage being lowered on to its tailwheel for this purpose.*

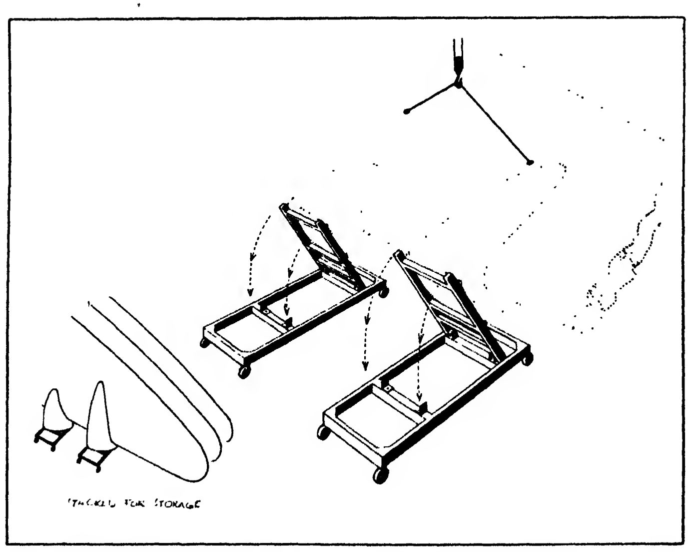


Fig. 263.—*Method of storing wings on vertical position (left) on hinged frames on wheeled trolleys.*

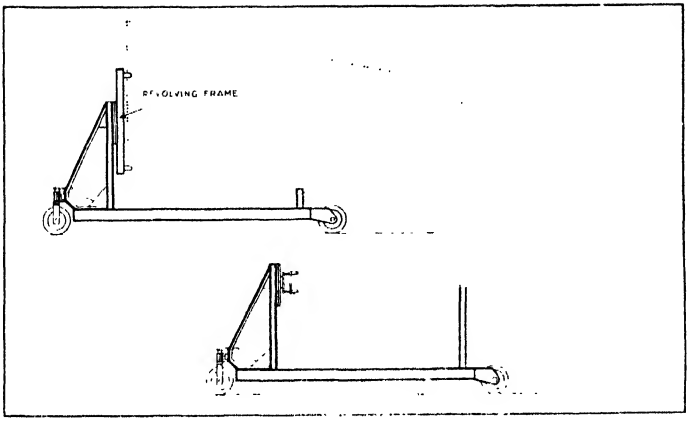


Fig. 264.—*For final assembly operations on the wing of the aircraft shown in Fig.* 262, *the trolley used has a revolving frame. The wing is bolted to the frame by its spar root fittings and can be turned into any position as required.*

Assembly Fighter Aircraft

The application of such equipment to a single-engined fighter type may now be considered. In this case, the principal components are front fuselage, rear fuselage, wings, and tailplane, the last being so light as not to require any special equipment. In many cases the assembly of wings to the fuselage has to take place at a considerable distance from the component assembly shops. As the undercarriage is mounted in the wings it was necessary to design all the equipment so that it not only provided working and assembly stands for the components, but also facilitated their transport, by towage behind light vehicles, over considerable distances, including many right-angled turns between buildings.

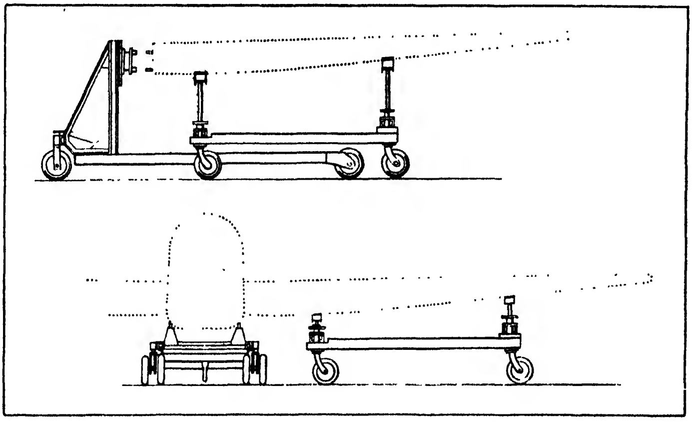


Fig. 265.—*To remove the wing from the assembly trolley a truck, with vertically adjustable cradles, is used. This truck can be run over the assembly trolley (left) to receive the wing and transport it in the flying attitude for offering up to the fuselage (below).*

For the front fuselage the truck was designed to support the component beneath the wing roots ; with toggle clamps for safety in transport and steerable pneumatic-tyred wheels. The rear spar support was designed to swing down to permit transport of the aircraft on the front spar and tail-wheel if desired. Fitting of the rear fuselage to the forward portion is carried out with a simple truck supporting the rear fuselage in felt-lined wooden formers.

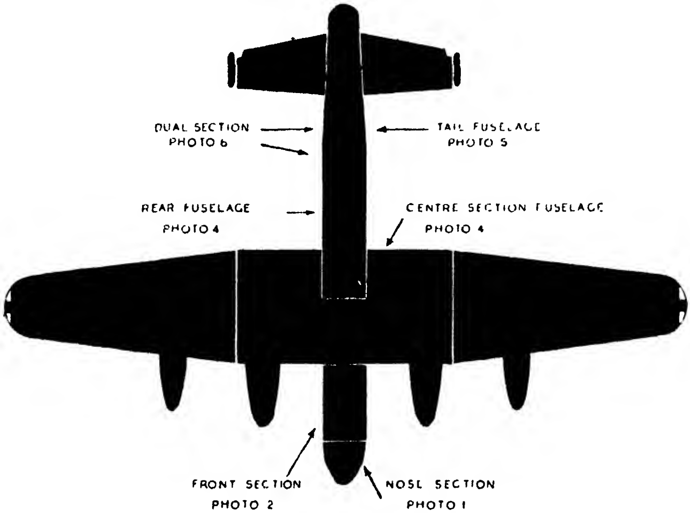


Fig. 266.—Sections of Lancaster in relation to the whole.

Wing Trolleys

The wings of this aircraft present a very interesting handling problem. In addition to the transport previously mentioned, there are many operations to be carried out after removal from fixture and before fitting the wings to the fuselage. Some of these require the wing to be vertical, some horizontal and some inverted. A truck was therefore developed, based on a design already in use, for a considerably lighter wing, consisting of a rectangular wheeled frame with a braced post at one end. On this post was mounted a frame, pivoted about a horizontal axis and fitted with forks to receive the spar roots of the wing. On removal from the assembly fixture, the wings are fitted to these trucks, which permit them to be turned readily into any desired position for access during assembly.

After the completion of all operations prior to fitting the wing to the aircraft, the wing is transported on this truck to the assembly point. For fitting the wing to the aircraft, a simple cradle-type truck is employed, adapted to run over the frame of the " turntable " truck, removing the wing from it and offering it up to the fuselage.

The principle of turning a wing section about a trunnion or similar mounting approximately on its centre of gravity has also been used in assembly of the Handley Page Halifax as well as in the United States of America, in the manufacture of Boeing B.17 wings and centre sections. Suitable frames are bolted to the attachment points with trunnion bearings adapted for lifting by means of overhead cranes. This method certainly has considerable advantages over those previously employed for turning wings about their main horizontal axis.

Fig. 267.—Lancaster nose section in course of assembly.

Fig. 268.—Joining nose section to front section.

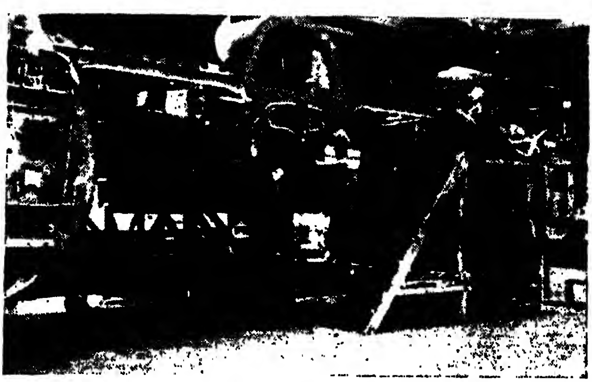


Fig. 269.—Centre section fuselage.

AIRCRAFT TROLLEYS FOR ASSEMBLING THE AVRO 683 LANCASTER 1

THESE trolleys, produced by George W. King, Ltd., of Hitchin, are specially designed to facilitate accurate and speedy assembly of the airframe. The plan view of the Lancaster bomber in Fig. 266 shows each section in its relation to the whole. The succeeding figures show in detail stage by stage operations by which these airframes are assembled. Prior to being placed on the trolleys, the components are lifted from the jigs by a specially designed overhead crane with a capacity of 2 tons. They are transported to the assembly shop and lowered on to the trolleys.

Fig. 270.—Wing turnover trolley.

Fig. 267 shows the nose section in course of assembly and in approximate position for joining to front section shown in greater detail on Fig. 268. All sub-assembly equipment and installation, electrical wiring, controls, etc., are carried out whilst the various sections are on the trolleys and when each appropriate section is joined to its partner, further work is carried out. Fig. 269 shows the centre section fuselage, relatively the most important part of the machine. Here technicians are busily engaged in completing the final work before the nose and front section are added to the main structure. Behind the centre section fuselage, the rear fuselage is to be assembled at a later stage, and to it is joined the tail fuselage before both are assembled to form the completed airframe. The assembly of the rear fuselage and tail fuselage is carried forward as far as possible on separate trolleys. As the work progresses, the two sections become one and this unit is placed on the "Dual" trolley shown in Fig. 273, where further work can be carried

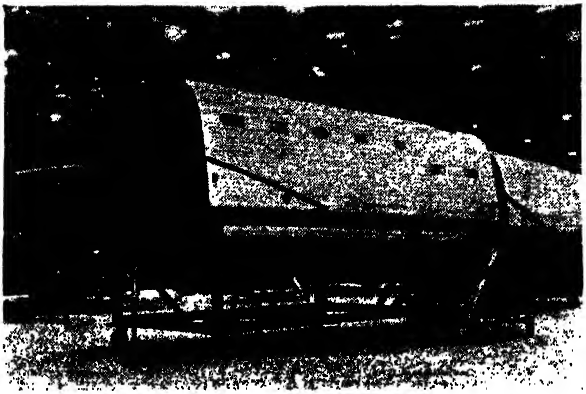


Fig. 271.—Rear fuselage.

Fig. 272.—Tail fuselage on trolley.

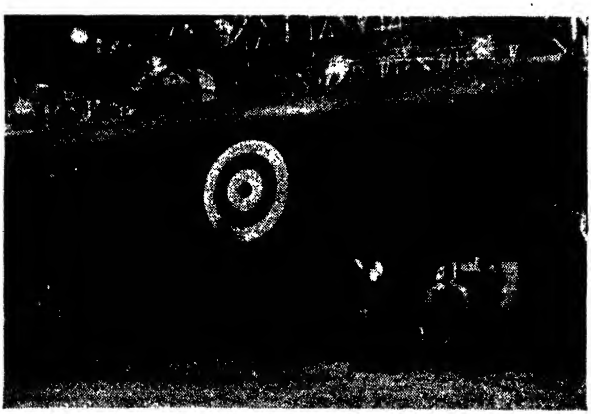


Fig. 273.—Rear fuselage and tail fuselage on "Dual" trolley.

out with greater ease. Complete in itself, this "Dual" section is attached to the rear of the centre section and so completes the final assembly of the fuselage. It is of special interest to note that these trolleys are so designed that when one section is offered in relation to another, the height has been accurately predetermined so that bolts, rivets and other methods of fixing is speedily accomplished. These trolleys are of light but sturdy construction, and fitted with swivelling castors. They offer a very valuable aid to aircraft work and are being installed in increasing numbers in many large factories throughout the country.

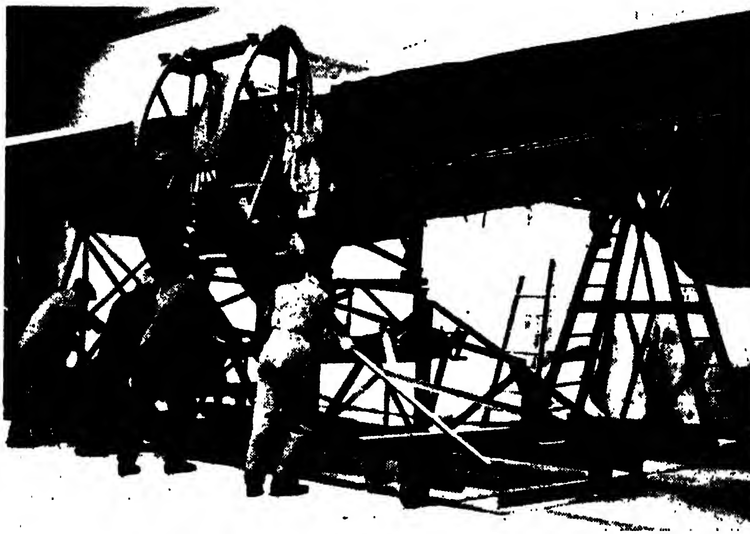


Fig. 274.—Another view of a wing turnover.

Wing Turnover

This is an especially designed appliance for facilitating the painting of aircraft wings. This equipment offers a rigid mounting for the completed wing and enables it to be rotated about its own axis through 90°. Thus, any part of the wing is accessible for inspection and the final work of painting prior to its attachment to the fuselage. A similar appliance, not illustrated, has been designed for handling the fuselage and performs a similar function with the added advantage of rotating the fuselage through 360°. Both these appliances can be considered essential to any programme which has in view high speed production with minimum labour.

ENGINES AND POWER PLANTS

Power Eggs for Merlin

One of the logical developments of aircraft design has been the introduction of unit-type "power eggs," comprising the engine and all accessories and connections. To ensure that these self-contained power units can be assembled, removed, or replaced, in minimum time, British engineers have perfected a system of power installation.

On present-day multi-engine aircraft, as distinct from single-engine fighters, it is now possible to attach a completely new power installation to one of the permanent bulkheads, couple up the various services, and have the engine ready to run within two or three hours. This system can, and probably will, be applied at some future time to new types of single-engine aircraft. To achieve this very desirable feature some ingenious designing work has been necessary and, consequently, engine mountings are now usually extremely interesting. A point of special interest is that a large and

powerful engine with all its equipment can be attached to the wing of a big bomber by just four to six cross-pegs, and yet stand up not merely to flying at high speeds, but also to shocks of heavy landings.

Unit Construction

The work consists of building the structure of the installation to the close limits necessary for complete interchangeability of even the smallest parts, to erect the engine in it, together with all components, subsidiary systems, and couplings for the services, and, finally, to install the cowling. When the unit leaves the factory it is entirely complete and ready for immediate service.

The essential feature of the Wellington or any similar mounting is that the relative positions of all the points of attachment to the bulkhead should be absolutely accurate in relation to the four points of contact of the engine bearers. Moreover, this relationship has to be established when the engine complete with accessories and components is in position, i.e., allowance must be made for the natural settlement of the structure

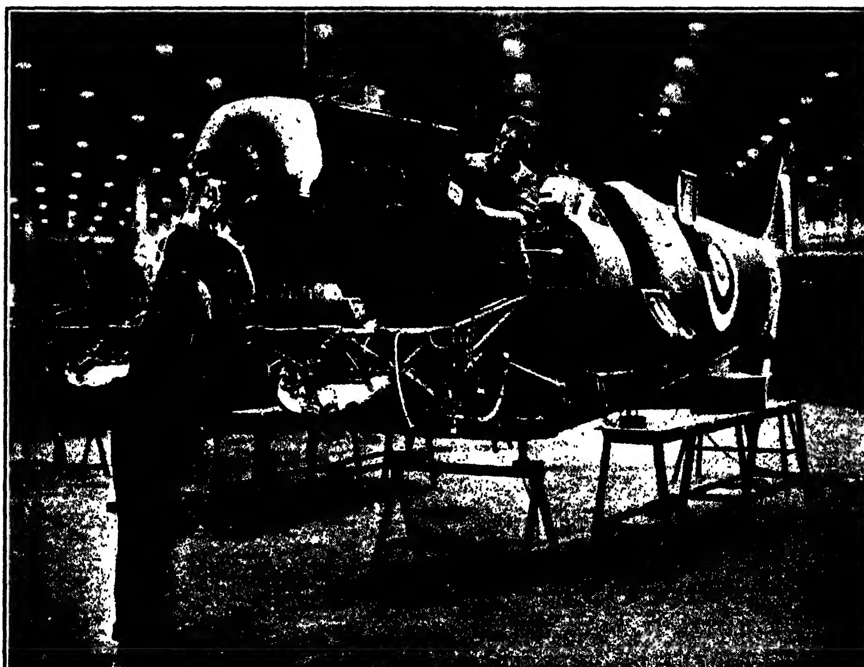


Fig. 275.—Lowering the Rolls-Royce Merlin XLV engine on to its mounting on Spitfirr.

when under load. To obtain the desired accuracy in a structure of multi-triangulated steel tubes (Fig. 282) nearly 6 feet long from base to apex, presents something of a problem. However carefully the individual struts, sockets and brackets are made there must be tolerances in manufacture, and it is possible, though perhaps not probable, for them to add up on the plus or the minus side. Where many different angles must exist, a variation of a fraction of a minute at one point of attachment of a strut may throw the opposite end of the strut a considerable distance out. In point of fact, the accuracy of building up has to be so close that not more than 5 lbs. pressure is required to pull a strut into position.

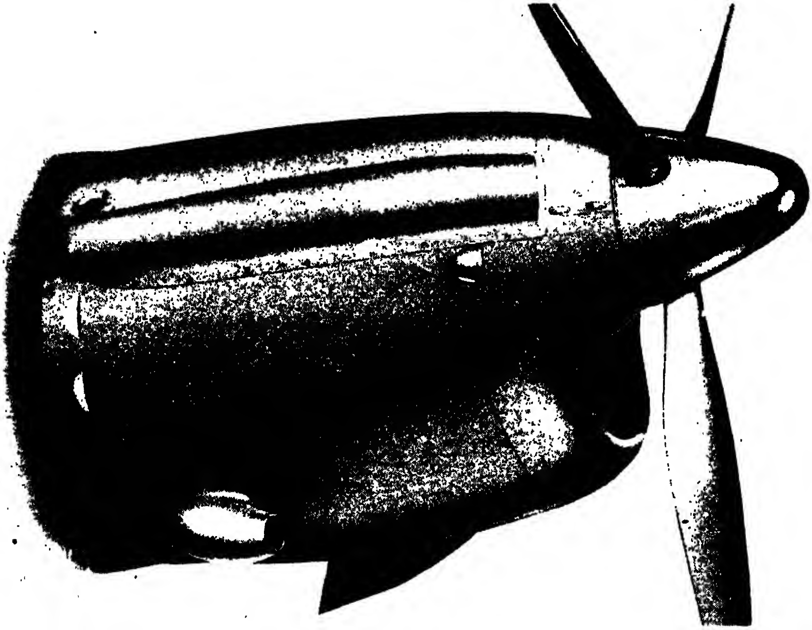


Fig. 276.—Merlin Power Plant in Beaufighter II.

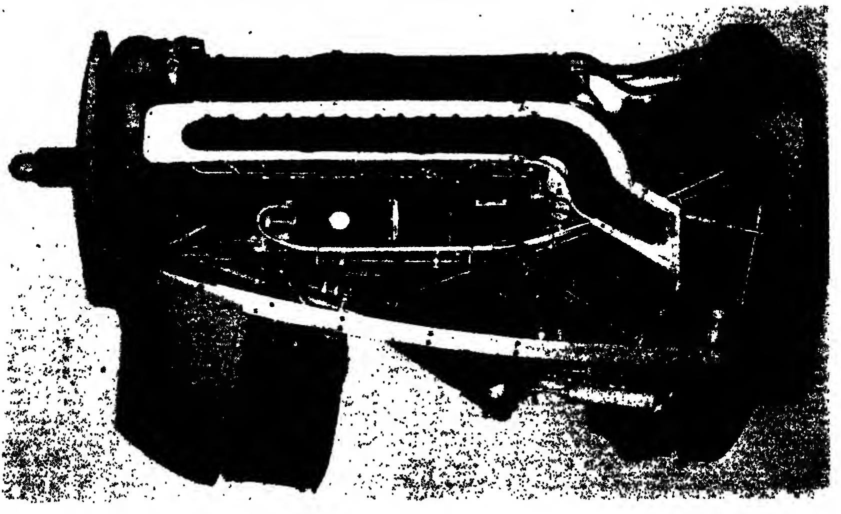


Fig. 277.—Left side of Starboard Power Plant, Merlin in Beaufighter II

The " Bristol " Hercules Standardised Power Plant

The scheme for standardised power plants has been evolved by British airframe and aero-engine manufacturers with a double purpose: first, to facilitate the installation of the engines in the airframe and, secondly, to minimise the lengths of the periods during which an aeroplane is out of service as a result of engine overhaul or repair. The Bristol Aeroplane Company's engineers pioneered the scheme; but since the Hercules standard power plant was first exhibited at the 1938 Paris Salon, certain changes in the external appearance have taken place due to advances in cowling and cooling technique and the additional requirements of present-day air warfare, and Figs. 278 and 280 show the present standard unit adopted for such aircraft as the Stirling and the Lancaster. The power plant is supplied as a basic unit suitable for any aircraft fitted with " Bristol " engines, while the airframe constructor fits the necessary aircraft services to suit his requirements.

The design, layout, and construction of this standard unit facilitates as far as possible both the first assembly in aircraft and the replacement of units under service conditions. Incorporated in the unit is the conventional engine mounting structure which terminates at a fireproof bulkhead in four jig located points designed for simple and easy attachment to the airframe.

The circular fireproof bulkhead is rigidly supported on the engine mounting structure, forward of the pick-up points, so that the complete unit can be slung in position, the attachment bolts be fitted and all connections expeditiously made; the provision of multiple-point plugs and sockets for all electrical connections being an outstanding advantage in speeding up operations.

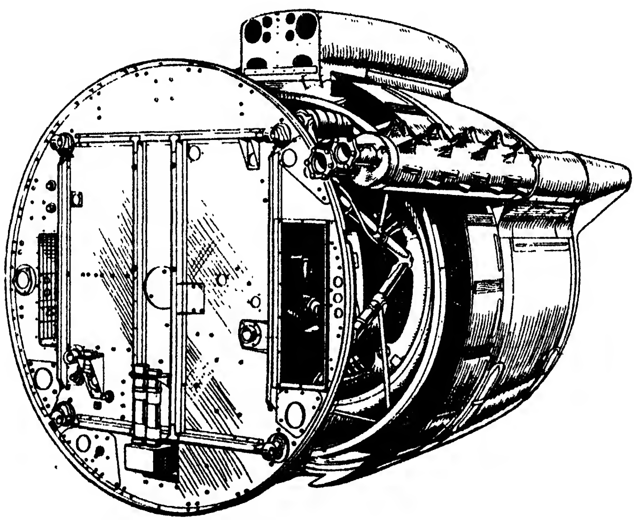


Fig. 278.—Hercules Power Plant, after end.

The mounting structure is arranged to give accessibility to the rear of the engine, carburettor, magnetos, etc.; and to meet the occasions when it may not be necessary to change the complete power plant, provision has been made for the engine to be detached from the mounting structure.

The fireproof bulkhead has grouped upon it the engine controls, fuel and oil pipe connections, electrical connections, and also the pyrometer and fire extinguisher connections. Provision is also made for the airframe constructor to mount the engine-driven " Bristol " Accessory Gear Boxes which provides mountings and drives of various speeds for up to six accessories to suit various combinations of the electrical, hydraulic and pneumatic equipment required on modern aircraft: this would also include propeller operating systems. As the combinations of these hydraulic and pneumatic accessories may vary with the type of aircraft and the engine station, the

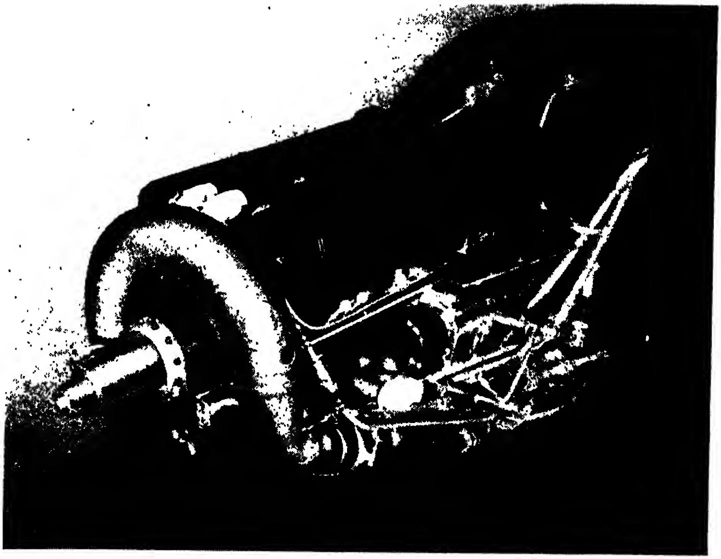


Fig. 279.—Rolls-Royce Kestrel in Miles Master.

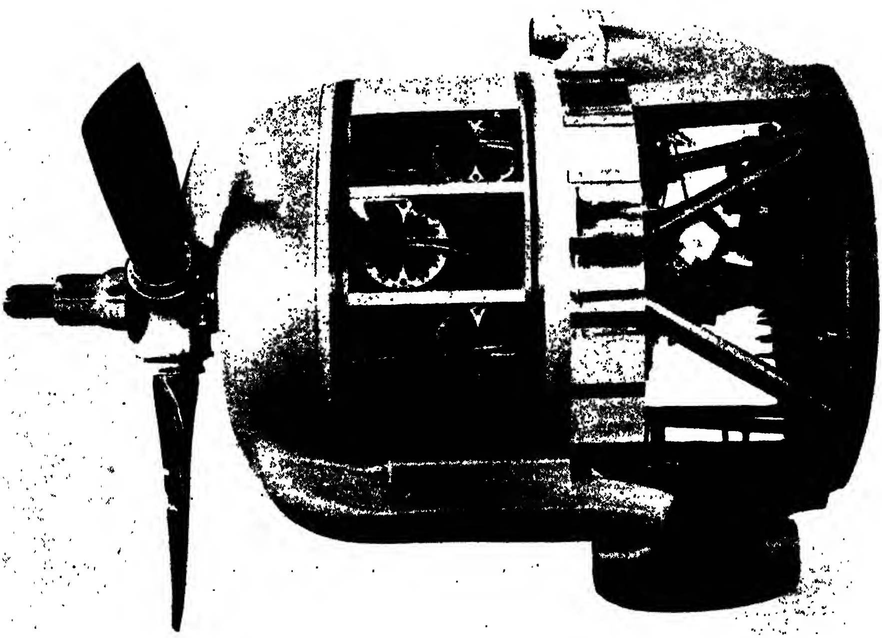


Fig. 280.—Bristol Hercules Standardised Power Plant.

connections are grouped on a panel and standardised to an Air Ministry gauge, provision being made to cover all actual or probable combinations of service. This standardised panel, which is an airframe supply, is a detachable fitting closing the opening provided in the bulkhead for its reception.

Provision is made for complete shrouding of the exhaust system to meet the requirements of aircraft engaged in night operations and the flame damping tail pipe is arranged to provide a supply of heated fresh air ample for direct cabin heating.

Specialised Staff

A specialised section of the manufacturers' staff, comprising the Engine Installation Design Department, deals with the development and design of these units, together with their related details, such as cowling, exhaust systems, air intakes, electrical equipment, cooling systems, and problems concerned with the reduction of drag, exhaust and flame damping and engine mounting, for their own particular type of engine. Manufacture of these units is on an entirely independent basis with a capacity to meet all demands for any type of aircraft As a result of the experience gained by their research departments upon installations operating under varying conditions, engine manufacturers are obviously in a position to supply the best design for each installation.

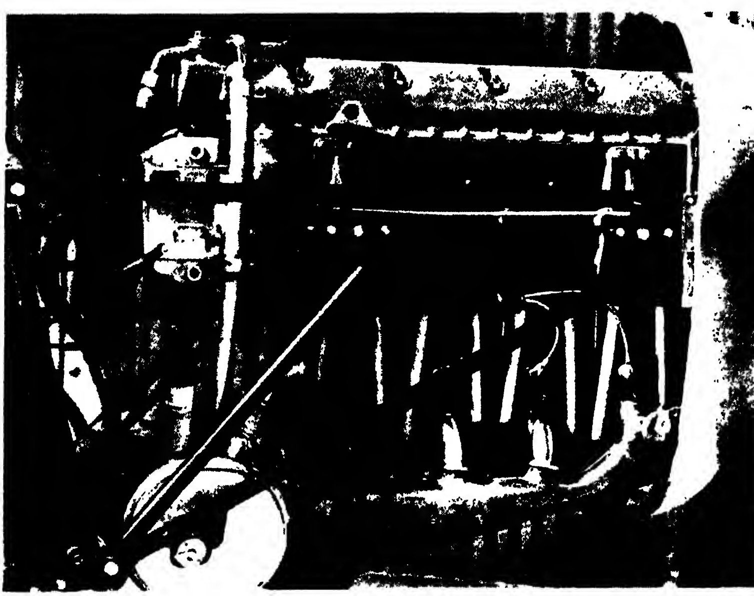


Fig. 281.—Installation of De Havilland Gipsy Minor Engine.

From the engine manufacturers' point of view, it has been highly advantageous to take over the responsibility for the supply of the complete power unit. Engine design right from the planning stage is now considered in relation to the airframe, whereas, previously, engines were often well advanced in development before this was even considered, frequently with unfortunate results to the aircraft constructor.

With both the Merlin and Hercules standard installations the engine mounting is so designed as to be suited to the whole series. The Bristol mounting has four and the earlier Rolls-Royce mountings had six pick-up points to the airframe structure and bulkhead to which all engine connections accessories are led. Spacing of these points is

standardised, so that it is possible to interchange power plants from the air-cooled radial to the liquid-cooled type, or *vice versa*, if necessary. This has actually been done to suit special conditions on some of our bomber aircraft service.

It will be seen, therefore, that not only does the system permit power plant replacement to be effected in the shortest possible time, but, in addition, facilitates the changing of a type without structural modification.

Jigs and Fixtures

To achieve interchangeability down to the smallest part, and to the close limits necessary, and at the same time maintain the necessary tolerances for manufacture, numerous jigs and checking fixtures are necessary for building the structure on production lines. In this respect the many sub-contractors engaged upon this work during the war have shown great ingenuity, for a considerable amount of semi-skilled and unskilled labour has had to be employed on this highly accurate work. In both cases the engine mounting is a triangulated, welded steel-tube structure. An essential feature of the Merlin mounting is that the relative positions of all points of attachment to the airframe must be absolutely accurate in relation to the points of contact of the engine bearers. Allowance must be made for the natural settlement, or sag, of the structure when under load.

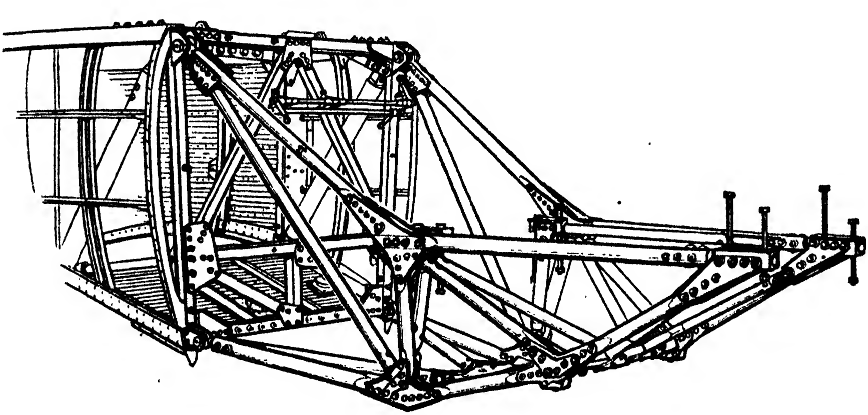


Fig. 282.—Triangulated structure for Rolls-Royce Power Plant.

In the case of the Hercules power plant, the standard cowling is provided as far aft as the engine mounting ring, including the controllable cooling gills. With the Merlin installation the cowling is provided up to the fireproof bulkhead, and, in addition, includes radiator, radiator control and assembly header tank. The fireproof bulkhead is not always supplied with the unit, but in any case conforms to standard design.

On the Hercules installation (Fig. 278) it will be seen that provision has been made for the complete shrouding of the exhaust system necessary for night operations. The flame-damping exhaust tail-pipe incorporates the cabin air-heater pipes. An example of the practical value of the system of allowing the engine manufacturers to supply the complete unit in this way may be quoted in connection with the Avro Lancaster. An important factor in rapid development and production of this machine was the fact that Rolls-Royce, Ltd., undertook the whole of the work necessary in connection with cowling and ducting of the Merlin engines, so permitting the aircraft manufacturers to concentrate upon the airframe proper.

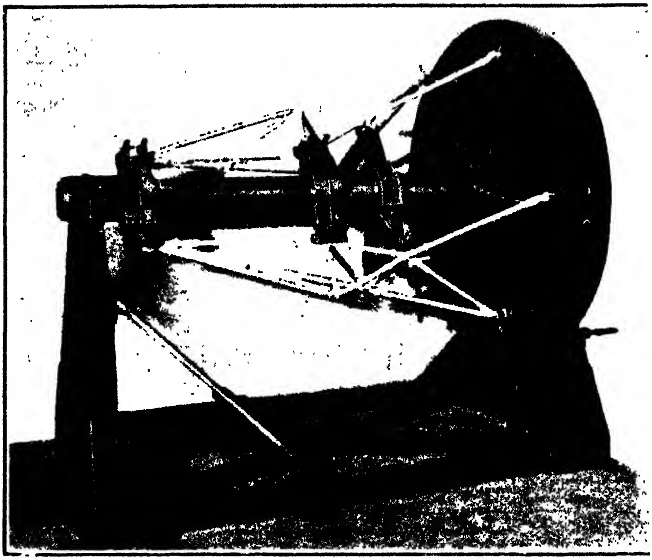


Fig. 283.—A rotary master fixture for checking the accuracy of mounting.

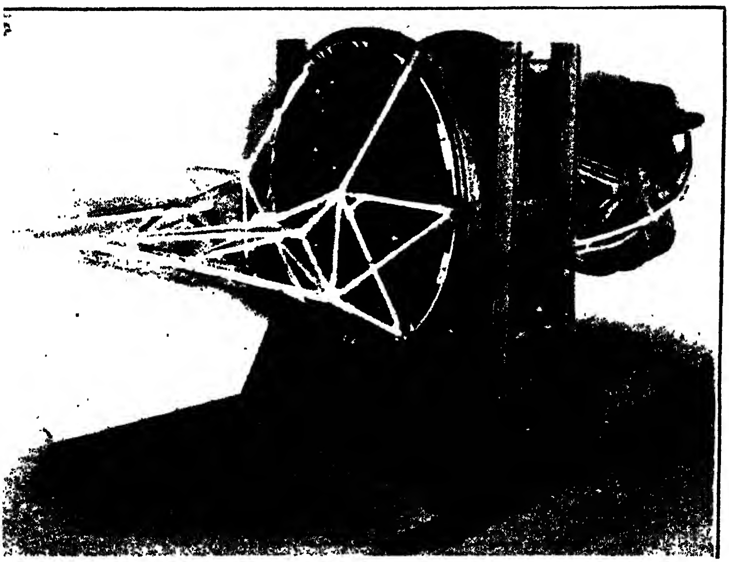


Fig. 284.—Stand for testing mounting bearing weight of engine.

PROPELLERS

Rotol Variable Pitch Propellers

WHETHER electrically or hydraulically operated, the variable pitch propeller is the only answer to a problem which faced aircraft designers in the past, when improvement in aircraft performance was hampered by the fact that fixed pitch could only provide efficiently for one particular condition of flight. The pitch of the blades required to provide sufficient engine r.p.m. and thrust for the take-off of a heavy machine was too fine for high speeds at altitude, while a pitch coarse enough for high flying speeds was not compatible with good ground performance. At best, fixed pitch could only be a compromise, or otherwise designed with a view to particular characteristics of the aircraft for which they were intended.

The hydraulically operated propeller with an alternative of two pitches was the first to appear, and later the constant speed type was put into service. In the latter case the blades could be turned to any point in the twenty degrees of its range. The operation was automatic, being governed by a constant speed unit which adjusted the blades to maintain any particular engine r.p.m., previously selected through a cockpit lever. By means of this unit the propeller maintained any predetermined engine speed by varying the load on the engine so that r.p.m. remained constant during any manœuvre of the aircraft. The range was increased to 35° for fast aircraft, and subsequently feathering propellers for multi-engined aircraft were developed.

The electrically operated propeller, through automatically or manually controlled current flow, combines the functional advantages of previous designs in that it can be flown as either constant speed with an adequate pitch range, or fixed pitch, when the blade angles can be adjusted at will. It can also be feathered quickly in emergency

This double method of operation increases reliability, and the fixed pitch feature enables a check to be kept on engine operation, and ignition and mixture systems.

The ability to feather the blades also adds to security, since the elimination of windmilling greatly facilitates flying an aircraft with one engine "dead."

Rotol Electrically Operated Propeller

Stripped of its pitch changing mechanism and current relay system, the Rotol electrically operated propeller comprises only three blade assemblies and the hub in which they are mounted. This hub is hollow and embodies a central buttressed protruberance which juts roughly halfway into its interior and is splined to take the drive of the shaft. The propeller is pulled up between two cones on the shaft by a hub nut which is locked to an extractor nut, of opposite hand thread, by the engagement of a locking plate with the hexagon of the former and the slots on the latter. Movement of one nut in relation to the other provides a vernier adjustment, permitting the hub to be pulled up solidly.

The blades fit into the three short barrels of the hub which are threaded internally to take the bearing housings. These housings each contain four bearings which bear internally against the steel adaptors at the roots of the housings, and externally against the inner surfaces of the housings. These bearings, besides permitting the blades to be rotated in the hub, carry the journal loads, the three inner bearings serving also to counteract centrifugal pull. The top bearing is used for preloading the other bearings of the stack, thus taking up any initial clearance in the assembly.

Pitch Changing Mechanism

The pitch of the blades is changed through the power unit, which consists of a 24-volt electric motor mounted on a reduction gear at the front of the hub. The series-wound motor is driven directly off the aircraft batteries and has two sets of field windings to accommodate reversible rotation. Its action is geared down by a crypto-epicyclic reduction gear, to drive a master bevel which meshes with three other bevels, one at the base of each blade adaptor, anti-clockwise rotation of the motor turning the blades to fine pitch and clockwise to coarse. Current for the motor passes through the slip rings at the rear of the hub and thence, by means of internal leads in the hub and reduction gear, to the motor. Three of these slip rings are for the coarse, fine and feathering circuits, and the fourth is the common negative.

At the front end of the motor is a brake lined with friction material and operated by a solenoid and springs. The forward face of the brake is attached to the motor armature shaft and rotates with it. When the circuit to the motor closes, the solenoid becomes energised and holds the rear face away against the springs. With the circuit

open and the solenoid inoperative, the brake is engaged and the motor and master bevel held. Overrunning of the motor and creeping of the blades are thus prevented.

Incorporated in the reduction gear are three mechanical cut-outs, operating through cams to break the electrical circuit between the hub and reduction gear when the operating limits are reached. These cams act upon the spring-loaded contacts in the reduction gear to lift them away from those in the hub, when the blades reach their maximum fine, coarse or feathered angles.

A mechanical fine pitch stop is fitted to prevent the blades turning past the optimum fine pitch angle should a mechanical failure take place or the electric cut-out fail. On no account must the motor be operated while the power unit is off the propeller with the stop in position, as the electrical cut-outs are inoperative under these conditions. If the motor has to be run for any reason while off the hub, the stop should be removed, but it must be replaced in its inverted position before running the motor, to prevent oil leakage from the reduction gear housing.

Control System

The electrically operated airscrew can be flown as either a constant speed or fixed pitch unit; in the latter case, the pitch of the blades can be adjusted at will by means

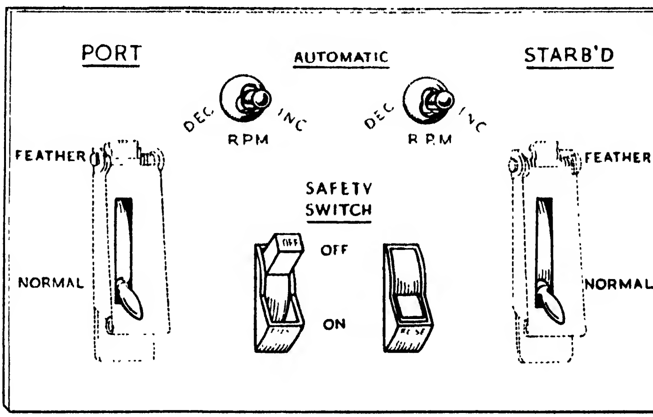


Fig. 285.—Layout of Cockpit Switches.

of a selector switch in the cockpit (see Fig. 285). This selector switch is of the three-way toggle type and governs the operating condition of the airscrew. The upward position of the switch is " automatic " and in this the airscrew is controlled by the constant speed unit. In the central position the circuit is open, the brake engaged, and the blade pitch fixed. However, from the central position the switch can be pressed downwards to left or right with the result that current is sent through either the coarse or fine pitch circuits respectively to move the blades as required. The switch must be held in either of these positions, as on release it springs back to the centre and the blades become locked in the obtaining pitch.

The whole circuit of the propeller is governed by a thermal throw-out switch which fulfils the duty of both a master switch and a fuse to protect the circuit from possible overloading.

A third switch is provided for quick feathering. It controls a voltage booster which is in series with the battery and consists of two distinct windings wound on one armature core and having a single field system which raises the voltage available from 24 to approximately 96 volts. This circuit is through the separate feathering slip ring, and the operation takes only a few seconds.

Feathering can also be effected by the use of the selector switch, the time taken being longer but the current consumption substantially reduced.

Constant Speed Operation

With the selector switch in the automatic position, the propeller operates through the constant speed unit; the action of a fly weight governor in the constant speed

unit controlling the direction of current to increase or decrease the blade pitch as engine r.p.m. tends to fall or rise. The unit is driven off the aircraft engine and its fly weights are thus directly sensitive to variations in engine speed. Their inward or outward movements act upon a valve, in a ported sleeve, which controls the flow of oil operating a spring-loaded piston balanced against engine oil pressure. The piston carries a contact connected with the positive feed, and it moves between the two "fixed" contacts of the coarse and fine pitch circuits.

The "fixed" contacts are actually in constant movement, being actuated by a spring-loaded plunger, in contact with a worm-operated cam. A small change in engine r.p.m. will cause the piston to move the centre contact very slightly so that the circuit

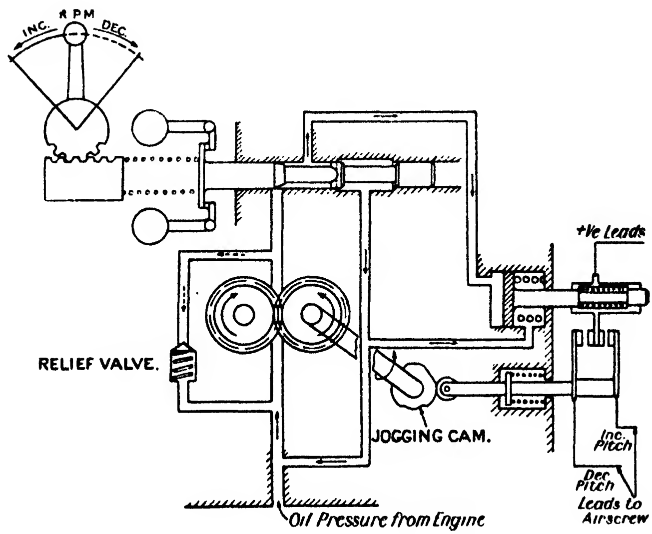


Fig. 286.—Airscrew Circuit.

is only closed momentarily and over-correction of the blade pitch is avoided. Large variations in r.p.m. hold the centre contact against the appropriate "fixed" contact until the blades have nearly reached the required pitch. The piston again moves towards its balanced position and contact becomes intermittent, resulting in an accurate pitch setting, with no accompanying "hunting." This characteristic is termed proportional governing.

The constant speed unit also has a small booster pump operating in conjunction with a relief valve. This ensures a constant and even pressure of oil to the control valve irrespective of alterations of engine oil pressure at changing r.p.m.

The control of the constant speed unit is effected by a spindle which is linked to a control lever in the cockpit and bears upon a spring in the constant speed unit. This spring balances the effect of the fly weights, its compression being adjusted by the lever over a range of possible values to determine the speed at which the engine must run.

When the cockpit lever is set to obtain a certain r.p.m. the fly weights and spring are so balanced that, with the engine running at this speed, the oil pressure valve is in a neutral position and the circuits are open. Any tendency towards an increase in r.p.m. causes a movement of the valve which allows pressure oil to the base of the piston, forcing it upwards until the controlling contact connects with the coarse pitch "fixed" contact. The blades coarsen and the engine speed is brought back to the required r.p.m. A falling off in r.p.m. is met by a movement of the blades to fine pitch, through a reduction in oil pressure at the base of the piston, which brings the controlling contact down on to the fine pitch "fixed" contact, by a change in position of the control valve.

To prevent wireless interference from both motor and constant speed unit a suppressor unit is included in the system. This is normally mounted on the front face of the engine bulkhead.

Inclusion of this suppressor unit in the system makes it unnecessary to screen the aircraft wiring up to the unit. The wiring to brush housing and constant speed unit forward of the suppressor unit is screened with a flexible metallicconduit.

Nose cap spinners are fitted over the reduction gear and motor assembly, a dust cover being provided for the electric motor. The spinner is cush-mounted and held in place by tabbed set bolts which screw, through the spinner shell, into tapped holes in the support plate at the front of the reduction gear. The motor dust cover is held by setscrews, and a dog on its periphery serves as a lock for the retaining ring which secures the motor to the reduction gear. Vernier adjustment is obtained in this lock by selecting the appropriate slot in the retaining nut.

De-icing Equipment

De-icing of Rotol propellers is effected by an electrically driven anticer pump, usually installed in the aircraft wing section near the fuselage (see Fig. 287). This draws de-icing fluid DTD.406a from a small supply tank and distributes it through pipes to a nozzle at the front of each engine. The nozzle directs the fluid into a rotating

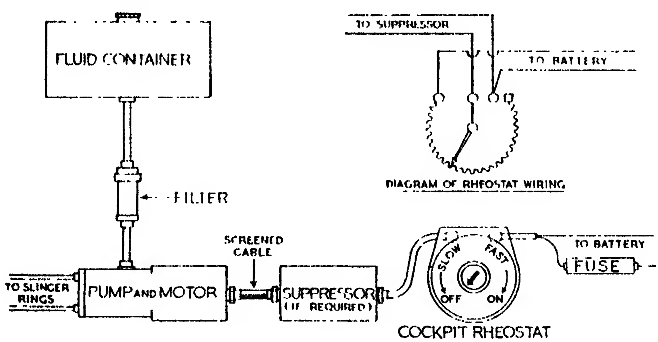


Fig. 287.—De-icing Circuit.

slinger ring, attached to the rear of the airscrew hub, and from this three pipes lead to the blade roots. Each pipe is coupled to a slinger ring horn by a rubber bush and is supported by brackets attached to the balance weight cover plate at the top of the bearing housing.

Attached to the blade adaptor is a trough of which the upper part is triangular and has at its apex a vertical nozzle which remains fixed at the leading edge of the blade (see Fig. 287). The hub-mounted pipe enters a slot at the base of the trough, so arranged that the stationary pipe can feed de-icing fluid to the moving trough at any point in the blade pitch range. Centrifugal force sends the fluid from the slinger ring to the trough and thence through the nozzle along the blade leading edge.

The operation of the pump is controlled by a rheostat switch in the cockpit which enables the pilot to control the rate of fluid delivery to the slinger ring.

A small flow of de-icing fluid, delivered periodically, is sufficient to keep the propellor blades de-iced. Fluid tankage is therefore kept to a minimum, which means that fluid must be used sparingly, otherwise the tanks will be drained in the early stages of the flight.

Rotol Hydraulic Propeller

The unit comprises an oil pump, centrifugal governor and slide valve, and is fed from the engine oil system. The pump portion of the unit consists of a driving gear in mesh with an idler gear in an oil tight casing. The driving gear has a long hollow shaft, one end of which protrudes from the face of the governor casing and is splined at the end to transmit the drive from the engine.

The idler gear has a short hollow shaft containing a non-return valve through which engine oil enters the casing and passes to the low pressure side of the gears. The oil is then pumped into a chamber in the shaft of the driving gear, from which two outlets are connected to the propeller oil pipes and a piston valve operated by the governor weights determines through which outlet the oil shall pass. When this valve is in a central position both outlets are closed and the high pressure oil from the pump by-passes through a relief valve back into the suction side.

Constant speed units for some installations have no external oil pipe connections and in such cases the coarse and fine pitch oilways from the driving shaft open on the mounting face of the unit. They align with two internal oilways in the engine casing which conduct the oil to the transfer at the rear of the propeller oil tubes.

The governor is mounted in a casing secured to the top end of the driving shaft and its pressure is balanced by a spring located between a flange on the piston valve stem and a rack or plunger which is controlled from the cockpit.

The short arms of the governor weights press against the outer race of a ball bearing secured on the piston valve stem so that the valve is pressed outwards by the centrifugal action of the weights and inwards by the spring. The initial compression of the spring can be set to any desired amount over a range of possible values, by means of the cockpit control, thus determining the speed at which the engine must run for the governor to balance the spring force.

Any tendency of the engine speed to rise above the required r.p.m. causes an outward movement of the valve. This results in pressure oil being delivered to the front of the cylinder and a simultaneous exhaust of the oil behind the piston back to the suction side of the governor pump. The pitch of the blades is thus coarsened to reduce the engine speed to the desired r.p.m., and the piston valve once more returns to the neutral position.

Similarly, if the engine speed tends to fall, the piston valve is moved so that it delivers pressure oil to the fine pitch side of the cylinder, causing the blade pitch to be reduced and the engine r.p.m. to rise to the desired value.

A further spring is fitted between the control rack and the casing and returns the rack to the position at which it maintains the engine speed at normal cruising r.p.m. should the control from the cockpit become disconnected.

Turning the governor control clockwise, i.e., to the feathering position, compresses this spring.

An adjustable high speed stop is fitted in the governor casing. It consists of a threaded stop making contact with the flat at one end of the control pinion segment and is set at the works to give the maximum r.p.m. of the engine for which it is intended by limiting the angular movement of the spindle.

When installing the unit, it is only necessary to set the spindle anti-clockwise against this stop and connect the control after setting the cockpit lever against its forward stop.

Feathering Propeller

The propeller is so designed that the blades can be feathered when necessary. The range of r.p.m. over which the engine is governed is represented by the travel of the speed control lever in the cockpit, from the forward or high speed position back to the stop which limits the lower end of the speed operating range. To feather the blades, it is necessary to lift the control catch and bring the lever past the minimum cruising stop, back to the extreme rearward end of the quadrant when the piston valve in the unit is lifted to the positive coarse pitch position. The coarse pitch side will then be open to the high pressure side of the pump. However, since the oil pressure falls as the engine speed decreases, it is necessary to augment the oil pressure in the constant speed unit. This is done by switching on an electrically driven pump which delivers oil from the main tank through a separate non-return valve to the pressure side of the constant speed unit.

When it is desired to unfeather the blades, the catch on the constant speed control lever is lifted and the lever moved forward into the governor range. This releases the piston valve from the positive coarse pitch position, and since the governor weights are stationary, the spring moves the piston valve to open the fine pitch oil pipe to the pressure side of the pump.

The feathering pump is then switched on and delivers pressure oil through the constant speed unit to the fine pitch side of the piston. As the pitch of the blades changes, the propeller is windmilled by the forward motion of the aircraft and the feathering pump can then be switched off. When the propeller is windmilling at reasonable speed the constant speed unit again comes into normal operation and the

ignition can be switched on and the engine restarted. The feathering switch is spring loaded so that it returns to the " off " position as soon as it is released. This ensures that the auxiliary pump shall not accidentally remain in action, although this would not in itself interfere with the normal constant speed operation of the propeller.

De Haviland Hydromatic Propeller

The Hydromatic propeller is basically similar to the bracket-type already in wide use, but it has a pitch range for constant-speed operation of 35° instead of the 20° of the bracket-type, while a further 45° of pitch range is available for feathering. This increased pitch range ensures satisfactory constant-speed operation under all normal conditions of flight.

The power required to feather the propeller is obtained from an electrically-driven pump, which is entirely independent of the engine, and so can be used even though the engine has failed. This pump is controlled by a push-button switch in the cockpit.

On single-engined aircraft there is usually little advantage in feathering the propeller, because an engine failure will in any case mean a forced landing. On such types, therefore, a slightly different version of the Hydromatic is used which still retains the 35° of constant-speed range but is not fitted with the auxiliary equipment required to feather. On some twin-engined aircraft the single-engined performance, with one propeller windmilling, is adequate, and on more such aeroplanes, especially of the fighter type, this modified non-feathering version of the Hydromatic is often used.

Construction

The main difference between the Hydromatic and the counterweight type lies in the pitch-changing mechanism, and also in the fact that the whole hub and pitch-changing mechanism are bathed in oil. Because of the latter feature, all openings between blade and barrel, spider and shaft, etc., have to be completely oil-sealed.

The propeller consists of three main assemblies :—

(i) Hub and blade assembly.
(ii) Distributor valve assembly.
(iii) Dome assembly.

Hub and Blade Assembly

The general arrangement of this assembly is similar to that of the counterweight type. Hollow shanked duralumin blades are carried on a spider which transmits the torque, the blades and spider being held together by the barrel, which takes the centrifugal pull of the blades. On the root faces of the blades are gear segments which mesh with the rotating cam of the pitch-change mechanism. The hub is secured on the propeller shaft by a split front cone and a large retaining nut.

A micarta collar is moulded on to the root of each blade between the duralumin of the blade itself and the thrust-race. This collar serves the purpose of ensuring a perfect seating for the bearing-race and avoiding stress concentrations, of insulating the blade from any vibrations which are transmitted from the engine and also of providing a good bearing surface for the oil-seal round the blade root.

Distributor Valve Assembly

The oil distributor valve assembly consists of an aluminium housing containing a spring-loaded valve which controls the feathering and unfeathering operations. In the housing are passages through which the oil is fed to the pitch-change mechanism. Attached to the inboard end of the housing is a tube which, when the valve assembly is in place, runs down the shaft. A sleeve, separate from the distributor valve assembly, fits round this tube and the two form the passages for supply of oil from the engine to the propeller.

Dome Assembly

The dome assembly contains the whole of the pitch-change mechanism. The dome itself is a duralumin forging and contains a piston having inner and outer skirts between which are four sets of rollers. This piston is made oil-tight in the dome by a large T-section seal. The movement of the piston in the dome is converted into movement at the blade roots through a pair of cylindrical cams, one inside the other. The outer cam is fixed through dowels to the barrel of the hub, while the inner is mounted on ball-bearings inside the outer cam and has at its inner end a bevel gear which engages

the gear segments on the roots of the blades. The rollers in the piston mentioned above run in slots in these cams. The slots are sloped in opposite directions so that, as the piston moves forward or back, the inner cam turns through twice the distance of the " lead " of the cam slots. From the base, for approximately three-fifths of their length, the cam slots have an easy slope, and this part of the slot gives the 35° movement of the blades required for normal constant-speeding. For feathering, a much steeper angle is used for the last two-fifths of the cam slots, and while considerably more pressure is needed on the piston to force the rollers up this steep slope, the rate of pitch-change of the blades is speeded up, and so the time taken to feather is very small.

The angles taken up by the blades in the full fine pitch and feathered positions are set by means of adjustable ring stops in the base of the dome which engage with stops fitted between the gear teeth of the rotating cam. Normally, no coarse pitch stop is fitted, as this would prevent the blades from being feathered, but the knee of the cam slots, where the change of slope occurs, acts in effect as a coarse stop pitch.

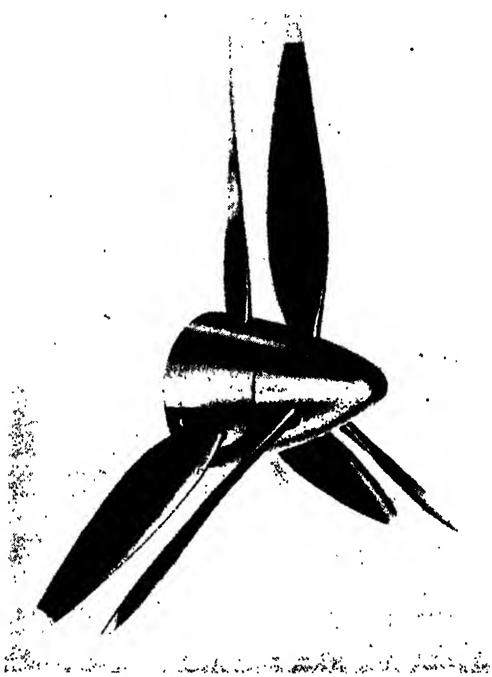


Fig. 288.—De Havilland Counter-rotating propeller.

Operation

The operation of the propeller is effected in the reverse direction to the counterweight type, i.e., oil from the constant-speed unit turns the blades from fine to coarse pitch, while the change from coarse to fine pitch is made by using the centrifugal twisting moment of the blades backed by oil at engine pressure. Oil is supplied through the tube and sleeve in the shaft, mentioned above on this page. The inner tube carries oil from the engine oil system and the outer sleeve carries oil from the constant-speed unit. With the distributor valve in its normal position the oil from the constant-speed unit is fed to the back of the piston, and the oil from the engine to the front of the piston.

Constant-Speed Operation

With the constant-speed unit control set for a given r.p.m. the following takes place if the r.p.m. begin to change :—

If the r.p.m. start to increase, the constant-speed unit supplies oil to the back of the piston and pushes it forward. The piston moving forward carries with it the rollers acting in the cam slots. This turns the rotating cam and, since this cam is geared to the blades, the blades turn towards coarse pitch. The increased pitch brings the r.p.m. down and so returns them to their previous value.

If the r.p.m. start to decrease, the constant-speed unit allows oil to drain from the back of the piston, and the centrifugal twisting moment of the blades, backed by oil at engine pressure, pushes the rollers down the cam slots towards the inner end of the cam and so changes the pitch of the blades towards fine pitch. This lets the r.p.m. increase and again returns them to their set value.

Feathering

When it is required to feather the blades, oil at approximately 400 lbs./sq. inch is applied from the feathering pump. This 400 lbs./sq. inch oil pressure is not sufficient to operate the distributor valve, and the oil therefore goes through the same passages as before. The high pressure, however, forces the rollers of the piston over the knee of the cam slots and right forward into the fully feathered position. Once the blades are in the fully feathered position, there is no tendency for them to move and the pump is stopped automatically by a cut-out switch in the oil line.

Unfeathering

To unfeather, a pressure of about 500 lbs./sq. inch is required. This pressure is again supplied from the feathering pump and is sufficient to overcome the spring of the distributor valve and move the valve forward so that the oil feed direction is reversed and the high pressure oil is fed to the front of the piston. This high pressure oil pushes the piston back and so unfeathers the blades. When the rollers have passed over the knee of the cam slot, the feathering pump is stopped by releasing the switch in the cockpit and the propeller returns to normal constant-speeding.

De Havilland Propeller Developments

The de Havilland Aircraft Co., Ltd., is responsible for two developments which have been proceeding in secrecy for a long time. One is the de Havilland all-metal four-blade propeller and the other is the de Havilland counter-rotating propeller. Both, of course, have full constant-speeding and feathering action.

Both developments have arisen out of the phenomenal advance in the supercharging of big engines, increasing their operating altitude to such a degree that three blades cannot provide enough blade area to work effectively in the rarer atmosphere, except if the propeller be made so large that it cannot be accommodated without unduly tall undercarriage legs.

All-metal Four-blader for 2,000 h.p. and Higher

The first of the de Havilland four-blader series was the size to suit engines of 2,000 h.p. and higher, the biggest the R.A.F. is using at present. This has a maximum diameter of 16 feet. Other sizes are being built covering the range of operational horse-powers. The four-blader embodies all the same exclusive structural and mechanical principles that have proved their merit in millions of hours of flying in earlier de Havilland variable pitch propellers, the development and production of which have been pioneered by the company in this country since 1934.

All-metal Counter-Rotating Propeller

The de Havilland counter-rotating double propeller has three blades in each plane, and here again the familiar de Havilland actuating principles and construction are preserved. The propeller is being made in a range of sizes and its development proceeds in unison with the development of modified engine reduction gearing.

An important feature in both propellers is the use of metal blades. These make possible the thin blade sections necessary for obtaining the last ounce of efficiency, also the relatively small blade roots which permit the use of correspondingly small hub, with reduced weight and cleaner spinner profiling. Furthermore, the high serviceability of de Havilland metal blades has been a feature in the conservation of the R.A.F. equipment in every theatre of war. In forced landings with undercarriage retracted such as sometimes occur on active service, the strong, malleable duralumin blades can

be relied upon to bend backward and from skis, protecting the main body of the engine and the whole airframe, and localising the damage. As for the blades themselves, 80% of those which are damaged in crashes or by gunfire (including those "holed" by bullets) are repairable and go back into service; only duralumin blades can "take it" in this way.

Curtiss Counter-Rotating Propeller Using Electric Control

This six-bladed dual rotation propeller, built about the principle of electric control of the pitch of its hollow steel blades, has been specially designed for aircraft engines of 2,000 horse-power upwards.

Several of the new type propellers, which American engineers expect to greatly increase the speed and efficiency of high-altitude flying, are being delivered to the United States Army Air Corps for installation on U.S. fighting planes.

The dual rotation propeller is, as its name implies, two propellers. These propellers are mounted on concentric, or coaxial shafts, which are driven by the engine, or engines, in opposite directions.

The control of the propeller is accomplished automatically by a constant-speed governor; or it may also be accomplished manually by a switch. Either method of operation is at the option of the pilot.

The dual rotation propeller has five outstanding advantages:—

(1) It eliminates the torque, or twist effect, of a single propeller. In single-engined, high-powered aircraft, the new propeller greatly improves lateral and directional control—under both low and high speed conditions—thereby increasing manœuverability and safety. The elimination of the rotational component of the slip stream has the further advantage that directional trim does not change with power on, or power off, as is the case with single rotation propellers.

(2) It increases propeller efficiency by approximately 5% for high-speed aircraft.

(3) For a given installation the dual rotation propeller is smaller in diameter than a single-rotation propeller, thus making possible a number of economies in aircraft design.

(4) Power-plant installation is simplified in dual-rotation, as it is not necessary to provide for as much torsional deflection in the engine controls, etc., as in the case of single-rotation propeller installations.

WEYBRIDGE PROPELLER BLADES

By F. C. LYNAM, *F.R.Aero.Soc.*

Blade materials have been the subject of many articles, and depending upon the blade type with which the writer of the article is interested, so the merits or demerits have varied. For any well-designed propeller, whatever the materials of construction, the aircraft performance, if viewed as a whole, should not be materially affected. For example, if any one propeller designer were given a free hand and was asked to design a series of propellers in different materials, all for the same specification, little variation in the final result would be expected.

In actual practice, however, we are faced with the fact that engine gear ratios have been fixed for, say, a metal blade design, hub-socket size fixed for the highest C.F load likely to be encountered, and the power available for the angular movement of the blade in flight settled for a blade width which is smaller than the one we want to use.

Such factors should be taken into account when enumerating the merits or demerits of any particular blade. It should also be remembered that the requirements of production must be studied by the designer, for he may so specify his blade scantlings that, for the sake of one m.p.h. increase in top speed, the blade output of the factory is reduced, due to the longer man-hours required.

The designer should also remember that even if he succeeds in obtaining, for example, a very thin blade with a knife trailing edge, the first run up on a sandy aerodrome will cause the edge to vanish and performance to fall away and, in addition, give the Service additional work in repair—that is, if they have not already decided to remove the offending parts before operational use. The evidence of tests on these special blades is of interest, but is not of paramount importance; the important part is the Service report after a few thousand blades have been in operational use.

Reverting to the product of the Airscrew Company, the Weybridge blade: this has been developed, as it was, and is, considered an easy production job, due to the availability of raw materials and to the easy adaptability of construction for any particular type.

The features which are of interest can be divided under the following headings:—

(1) Strength and weight.
(2) Aerodynamic performance.
(3) Repairs.

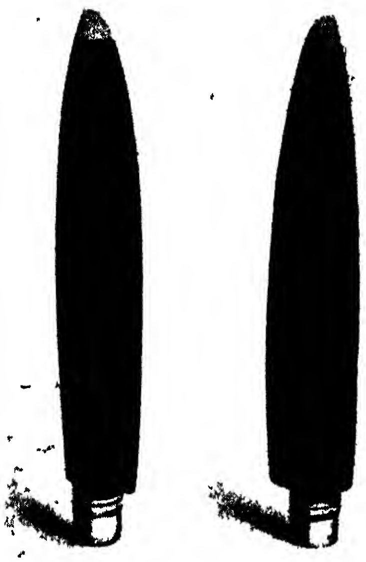


Fig. 289.—Weybridge propeller blades.

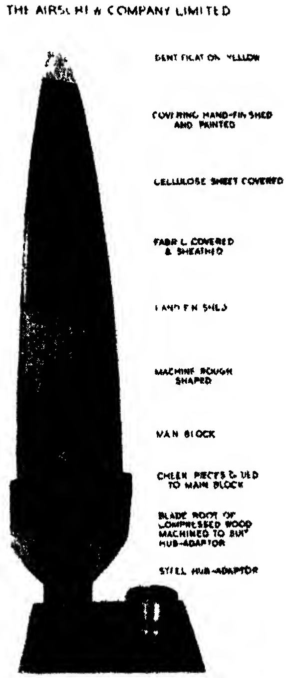


Fig. 290.—Stages in manufacture.

Strength and Weight

The materials of construction for Weybridge blades have been explained many times before, but, briefly, the operational part of the blade is composed of softwood having a specific gravity of 0.5, and therefore under running conditions a low centrifugal force results. As an example, the weight of a Weybridge blade for a propeller diameter of 12 feet 9 inches is made up as follows:—

Hub adaptor (steel)	12½ lbs.
Compressed wood root	15 lbs.
Softwood blade	16 lbs.
Protective covering	3 lbs.
Total	46½ lbs.

At a rotational speed of 850 feet per second the centrifugal load is only 50,000 lbs. The blade root for this particular blade is capable of withstanding a load of approxi-

mately 100 tons before failing by shear along the threaded portion. It is therefore evident that an ample factor of safety is available for normal blade loadings.

With increased engine power and operational height it has been necessary to increase propeller size by increasing the aggregate blade width; the designer of metal blades will prefer to increase the number of blades rather than increase the individual blade width, due to the abnormal increase in weight. The width of the wooden blade, exemplified by the Weybridge type, can be increased considerably, at the same time reducing the thickness-chord ratio of the aerofoil sections as far as flutter considerations will permit. With the case mentioned above, for a diameter of 12 feet 9 inches the solidity can be increased by 30% for an increase in the weight of softwood from 16 lbs. to 23 lbs., which is an increase on the total blade weight of only 15 lbs.

The steady stresses in the blade are always well within the allowable limits because blade scantlings are in most instances decided for reasons of flutter, a feature which the Airscrew Company have made a special study. They are therefore in a position to obtain the most suitable blade form for a minimum weight. The factor which works against the use of wide blades is the increased centrifugal twisting moment, although for a given solidity the propeller with the smaller number of wooden blades should normally have a slightly lower twisting moment than the corresponding metal type with more blades.

In general, therefore, the Weybridge blade should show advantage when increased solidity is required without the inclusion of more blades: efficiency will increase, due to lower thickness chord ratio and the increase in weight will vary only slightly more than the increase in chord size.

Aerodynamic Performance

It is the propeller's task to transform the engine power into useful thrust power, and this the wooden propeller blade does over the gamut of performance with as much all-round efficiency as other types. The difference between the engine power and the useful thrust power represents the losses incurred in this transformation; these losses are generally divided into:—

(1) Induced losses.
(2) Compressibility losses.
(3) Profile drag losses.

The induced losses for a given engine-aircraft installation are mainly dependent upon the propeller diameter and number of blades; as each increase, the induced losses should get less, although at an increasingly reduced rate. The compressibility losses are governed by the helical tip speed of the blade, the blade incidence, blade chord and section thickness-chord ratio, and the speed of sound of the air in which the propeller is working; these factors interact one with another so that any complete exposition would take many pages, but it may be briefly said that as helical tip speed/speed of sound ratio increases so do the compressibility losses; at top speed (low incidence) increase of t/c ratio for a given diameter increase losses, but at climb and take-off (high incidence) increase of t/c ratio decreases losses.

All propeller blades are forced to operate over a range of incidence from the stall at take-off to low incidence at top speed, and over a range of compressible flow conditions. As stated, these conditions mutually effect the efficiency; in some cases the engine and aircraft condition are such as to make the Weybridge blade slightly less efficient at top speed than the corresponding metal blade—this is due to the blade section thickness-chord ratio for the normal wooden blade causing slightly worse compressible flow conditions than the metal, but at the climb and take-off the position can be expected to be reversed; at cruising conditions there is no difference in efficiency to be expected between wood and metal blades. If conditions are such on an aircraft that the propeller diameter has to be restricted then the wooden blade has especial advantages in that very wide blades compared with diameter can be built whereby a saving can be effected in the number of blades required over types of construction which are forced to use smaller chords; in such cases the section t/c ratio can be reduced if it is considered desirable. The operating force needed for the propeller pitch changing mechanism varies for a given material and diameter approximately as the blade chord to the fourth power so that as the blade chord is increased the pitch changing force must be increased, but, so low is the Weybridge blade material density compared with, for instance, duralumin, that blade chords of up to 50% in excess of corresponding duralumin blades can be made without the pitch changing force for the latter being exceeded.

Weybridge blades have some special advantages, among which may be stated that of ease of conversion of the blade contour and diameter to suit new engine conditions

such as change of rated height, power or gear ratio. This means that in wartime, when such changes are common, the Weybridge blade can be modified quickly by building up to give a propeller which may avail itself fully of the changed conditions. Such a conversion is mentioned under "Repairs." Another advantage is that flared blade roots can be incorporated easily in the basic blade, and these flared shapes can be modified quickly if it is desired to experiment with the radial engine cooling.

The Weybridge blades have been built to operate in all the latest development types of propeller hubs, including the contra-rotating propeller.

Repairs

The most remarkable progress has been made with the repair of Weybridge blades since the war began; at the present time arrangements are being made to replace the whole of the softwood of the blade, and with this the percentage of damaged blades capable of repair will be of the order of 95%.

The normal repairs in present production are standardised as No. 1, 2 and 5 tip repairs, together with half-blade or maximum blade repair.

The main difficulty associated with repairs is to bring the blade back to one of the standard balance moments laid down for the blade type; this is not easy, as new material is being added to the blade and careful shaping is necessary to see that the standard absolute moments are attained.

Under Service conditions, especially abroad, similar repairs have been carried out, aircraft having been kept in operational use due to the ease with which repairs can be made. Where bad nose-down landings have occurred the wooden blades break, thus preventing the load being transmitted to the reduction gear of the engine; thus the blade which is easily repairable saves replacing engine parts which require more labour to produce and fit.

The popularity of the Weybridge blade is due almost entirely to the use of natural wood for the working part of the blade. It offers many advantages, i.e., for aerodynamic design, construction and repair. Wood in the form used is obtainable almost anywhere in the world, it is easy to handle, easy to machine and, weight for weight, is one of the strongest of materials.

ROLLING AIRSCREW BLANKS

Owing to a steady increase in the size of propellers used on modern machines, together with the higher speed of revolution, the question of reducing blade weight and also increasing the strength has become of paramount importance to aircraft manufacturers. In the case of metal propellers, reduction in weight has been achieved by the introduction of blades made from magnesium alloys.

However, owing to corrosion, erosion and fatigue, failure often occurs with blades made from this material, and although ordinary protective processes, such as chromium treatment, assist considerably, they do not provide a complete solution of the problem. It has been found that surface rolling considerably increases the fatigue strength of magnesium and aluminium alloys subjected to the stresses encountered in a propeller. For this reason the forging roll made by Eumuco, Ltd., is of particular interest, as it introduces a rolling operation into the manufacture of propeller blades.

Airscrew Production Process

Blades are produced by either stamping or pressing hot metal between dies, sufficient material being allowed for subsequent machining operations. Owing to the widely varying thickness and width throughout the blade, it is impossible to produce it directly from a bar or billet, as this would result in damage to dies and material. To overcome this difficulty an intermediate stage is introduced, in which the billet is shaped to more suitable contours.

In the past this dummy, or blank, has been made by forging the hot billet under a heavy drop stamp. Only a very crude approximate shape is obtainable, and there is quite an appreciable amount of surplus metal after final shaping in the dies. This results in unnecessary die wear. The surface of the dummy is not smooth, but is covered with a series of steps caused by the edges of the hammer block. The irregular deformation and compression produced by the heavy hammer blows undoubtedly weakens the metal through injury to the grain flow. Before forging the billet it is essential that the exterior is machined, in order to remove dross which may be hammered into the interior of the blade.

To overcome these disadvantages Eumuco, Ltd., of Barnes, have introduced a forging roll to replace the hammer previously used. It is claimed for this process that the grain flow of the material is improved, thereby increasing the fatigue strength, and that a considerable economy in metal is effected, in addition to a substantial increase of production rate. In the case of aluminium alloy blades the dummy can be rolled directly from an extruded billet without machining the exterior to remove dross. For magnesium alloy blades, however, machining is still necessary.

The general arrangement of the machine can be seen from the accompanying illustration. Essentially, it comprises two rolls, arranged vertically, which make one complete revolution and then stop. Cut into the surface of each roll is a groove corresponding to half of the section of the dummy. Several completed blanks are shown and it will

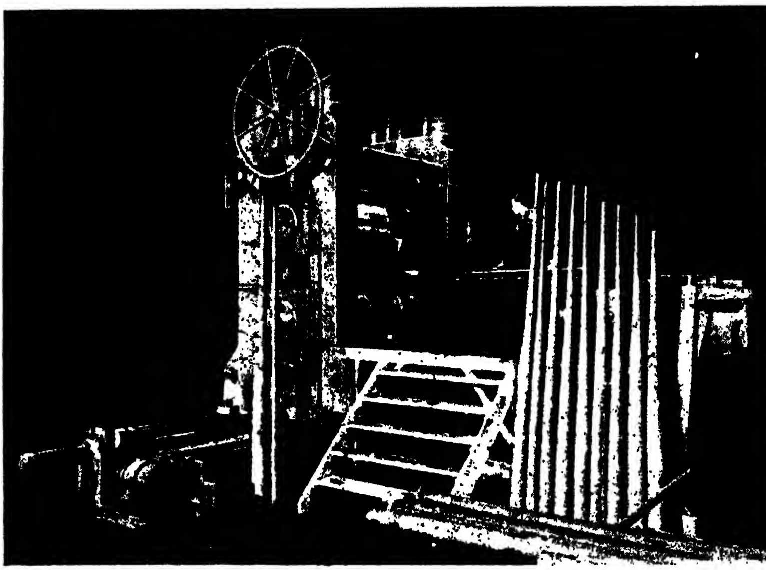


Fig. 291.—Rolling airscrew blanks prior to stamping or pressing operations.

be observed that these taper practically to a point. To produce this shape the depth of the grooves in the rolls is also tapered. Usually four grooves of different size are provided on each roll. This allows four sizes of blanks to be made without changing the rolls.

Arrangement for the Rings

The groove or impression is machined in a 15 inch wide steel ring which fits over the actual roll. If a long length of taper is required, the impression extends around three-quarters of the circumference of the ring, but if the taper is comparatively short only a half-ring is necessary. A sectional view of a pair of rings is given in Fig. 292 from which it will be seen that part is cut away to provide clearance. The rings are so arranged that, at the commencement of the operation, the two clearances face each other and provide sufficient space to allow insertion of the billet at the rear of the rolls.

Pressure on a foot control causes the rolls to rotate and feed the work towards the operator, the increasing shallowness of the groove tapering the billet. As soon as one revolution is completed the rolls cease to rotate, and the billet is moved back to the starting position. Usually several passes through the rolls are required, the actual number depending on the diameter of the blank, the material from which it is made and the shape of the dummy. Each successive pass commences at a position nearer to the root end of the blade.

Various methods are adopted for holding the billet, one of which is shown in Fig. 292. This consists of a length of steel bar screwed at one end to suit a threaded hole in the

end of the billet. The work is supported on some form of table extending as near as possible to the rolls. One of the most simple types is merely a length of vee-section channel iron along which the billet is moved. A more elaborate type of table incorporates a special carriage mounted on wheels. After completion of the first dummy the operator is able to make a series of chalk marks on the table, or arrange a set of stops, so that he knows just how far forward to move the billet for each pass of subsequent billets.

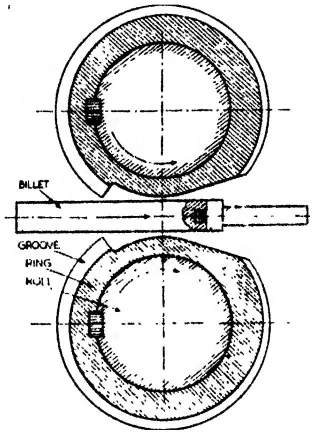


Fig. 292.—A sectional view of the rolls. It will be noted that the circumference of the roll is cylindrical and that the bottom of the groove is tapered in depth.

Heating the Billets

Adjacent to the machine is arranged either a salt bath or an electric furnace for heating the billets prior to rolling. When a salt bath is used it is necessary to clean the work, or damage may be caused when the liquid salt is removed by the rolls. Before commencing rolling the rings must be heated to the appropriate temperature and maintained at this figure throughout the process. This applies particularly in the case of magnesium alloys. Gas heating can be used, but an electric heating device, capable of accurate regulation, is available.

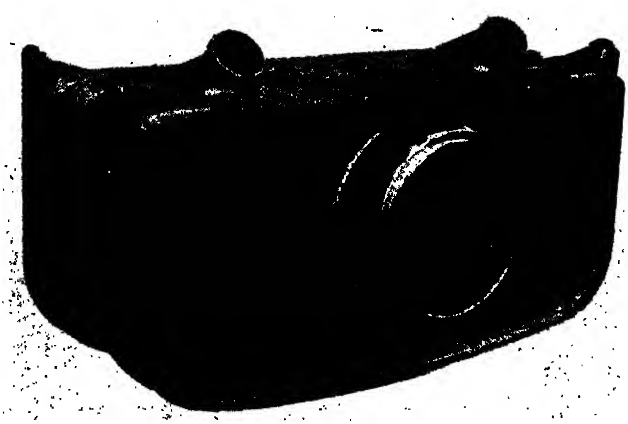


Fig. 293.—Radiator with oil cooler in middle, as in fighter types.

AIRCRAFT RADIATORS AND OIL COOLERS

RADIATORS fall into two distinct types, each of which has minor variations, but which may be referred to in general terms as the honeycomb type on the one hand, and the fin and tube or secondary surface type on the other. The honeycomb type has a matrix which may be built up either from solid drawn tubes expanded to a hexagon at the ends, or from seamed elements, each of which may contain a number of cells in the form of tubes, usually varying between two and five cells per element. These are secured to each other and to the case by solder, the tubes or elements to each other by dipping, and to the case by hand soldering. As the wall thickness of these tubes or elements is only of the order of .005 inch, and the casing thickness is kept to a minimum due to considerations of weight, it will be obvious that care must be exercised in mounting the radiator on the aircraft to ensure that it is adequately protected from excessive vibration as well as from undue stresses arising from too rigid mounting or distortion. Instances of trouble arising from these causes have in fact been recorded on a number of occasions.

The fin and tube type radiators are of similar light construction and require similar careful handling. In this type of construction, the complete matrix is immersed in a bath of solder which ensures good metallic contact between the tubes and fins, and the

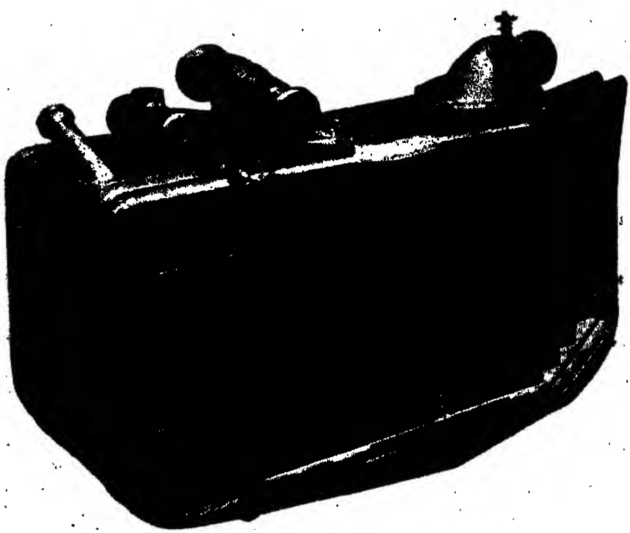


Fig. 294.—Twin-engine installation; two radiator sections and an oil cooler, for mounting in common air duct by tension bands.

tubes are soldered by hand into tube plates. The tube plates in turn are soldered to the tanks which form the inlet and outlet to the matrix and to which the inlet and outlet connections are fixed.

Radiators of both types are mounted on the aircraft either by bands round the radiators provided with tensioning device and located in channels provided for this purpose, or by means of lugs provided on the radiator on tubular framing forming part of the engine mounting or airframe, depending on location. In some recent types, the radiator forms part of the power egg including the air duct, and is then, of course, attached direct to the engine mounting. For both types of mounting it is essential to have rubber to isolate vibration, either as strips under the bands, or as bushes in the lugs. Rubber strips should also be fitted to prevent chafing between radiator and cowling.

Oil Coolers are practically all of the honeycomb type with solid drawn tubes, and are built up in much the same way as radiators. On air cooled engines they are almost invariably attached direct to the engine mounting and fitted with suitable duct or cowling. On liquid cooled engines the position and manner of mounting varies considerably, as will be seen from the illustrations.

Fig. 294 shows an engine set comprising two radiator sections and an oil cooler all of the honeycomb type with solid drawn tubes, and designed for mounting in a common air duct by tension bands. This is typical of many twin engine bomber installations.

Fig. 293 illustrates a radiator with the oil cooler mounted in the middle, as fitted to a well-known fighter, both radiator and oil cooler having solid drawn tube matrices. A variation of this arrangement incorporates the carburettor air intake through the centre of the oil cooler.

Fig. 295 shows a combined radiator and oil cooler of the secondary surface and honeycomb type respectively, bolted together and arranged for lug mounting in a common air duct.

The foregoing are typical of many installations with minor variations in design; but they do not cover all types, and more recent developments will be dealt with in the next issue of the YEAR BOOK.

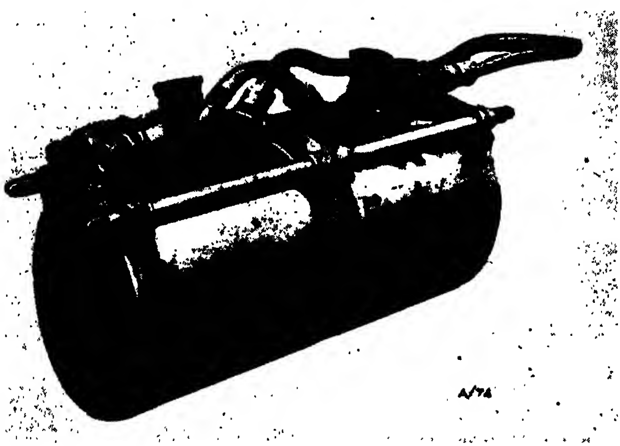


Fig. 295.—Combined radiator and oil cooler, arranged for lug mounting in common air duct.

Pipe connections are of three types, rubber hose with hose clips, screwed (including union) connections, and Avimo Couplings. All these connections allow very little latitude in the position of the pipes to which they are connected, and this should be carefully checked before making the joint, otherwise severe strain may be imposed on radiator or oil cooler which will eventually cause leakage. Another point to watch is that all pipe connections should be adequately supported so that gravitational loads are not imposed on radiator and oil cooler branches.

It is very important when installing either radiators or oil coolers to ensure that all air is excluded from the system, otherwise air locks may occur which interfere with circulation of oil or coolant, either of which would rapidly result in engine failure. Pet cocks are provided either on the components or pipe lines which should be left open until air has ceased to escape. (The header tank must not, of course, be completely filled, but only to the specified level, to allow for expansion.)

Due to rubber connections, and to a lesser extent paint, the radiator is frequently electrically insulated, and it is essential that, like every other part of the aircraft, it is bonded to the airframe to prevent the building up of a static charge and interference with wireless communication.

LANDING GEAR

Vicker's Oleo-Pneumatic Shock Absorber Unit

The Vickers Oleo-Pneumatic Shock Absorber Unit is an extremely simple piece of mechanism, designed to meet the requirements of each individual aircraft.

It consists chiefly of an air cylinder; sustaining ram (or piston); gland; hydraulic ram; damper valve; oil level tube; oil level plug; air valve and safety lock.

The weight of the aircraft is supported by the piston operating in the air cylinder which has been charged to a pressure sufficient to support the load at a predetermined piston position. During flight the air pressure will move the piston to its full extent. Upon landing, the blow will drive in the piston and compress the air until it balances the force of the blow, thus absorbing some of the landing energy. At the same time as the piston is moving in, the tapered hydraulic ram enters the oil chamber at the top end of the piston and forces oil through a narrowing annular orifice, which sets up a hydraulic resistance and destroys more landing energy. The remaining energy is absorbed by the tyre.

The energy absorbed by the air is employed to return the piston to its original position, but the velocity of the action is checked and oscillation minimised by the operation of the damper valve which controls the flow of the trapped oil behind the piston head.

The use of air as a springing medium results in a much lighter unit than when a steel spring is employed, also the air pressure can be readily adjusted to suit variations of load.

As the Vickers unit does not employ spring-loaded valves, or any complicated mechanism, there is little to gve trouble once the unit has been correctly serviced.

An endeavour is made to operate on an air pressure which, while reducing the size of the unit, will also be reasonable from a servicing point of view. The initial air pressure seldom exceeds 800 lbs. per sq. inch.

The oil employed is of the anti-freezing variety, and to specification D.T.D.44. All materials employed are to approved specification.

The units may be divided into four classes :—

(*a*) Simple strut units.
(*b*) Cantilever strut units.
(*c*) Frame type units.
(*d*) Retractable tail chassis units.

Class (*a*), as their name implies, are designed to support end loads only, and should be mounted between universal joints. These are generally used on non-retractable type undercarriages.

Class (*b*) is of the type used on medium and small aircraft where retraction of chassis is required. It is a single-strut undercarriage with the landing wheel mounted on a cantilever axle carried at the lower end of the piston. This results in offset and torsional loads in addition to the usual end loads being applied to the unit. In order to convey the offset loads from the piston to the cylinder with the minimum of bearing friction, the piston in its extended position has its head arranged at a reasonable distance from the gland bearing. The torsional loads are transmitted from the axle to the cylinder by means of links which have proved to be more efficient than splines on the piston, although this latter method is still employed on early units of this type. The brake reaction is transmitted to the unit by means of a flange machined on the axle.

The cylinder is attached to the aircraft by suitable means as required by the aircraft constructor.

Lugs are often formed on the cylinder for the purpose of mounting the fairing.

Class (*c*), which is used on large aircraft and is required to retract into the engine nacelle, consists of two units braced together at the cylinders. One landing wheel is mounted between them on an axle which is rigidly connected to the lower ends of both pistons by means of bearing-shaped fittings. Brake reaction is transmitted to the units by flanged sleeves fitted over the axle and keyed and clamped into the bearing fittings.

The cylinders are interconnected by a balance pipe in order to equalise the air pressure in both units.

The cylinders are mounted with suitable lugs and bosses for attachment to the aircraft, and for carrying fairing- and door-operation gear.

Class (*d*) is similar to the cantilever type, excepting that the wheel is mounted in a fork which is attached to the lower end of the piston, and a centralising cam is in-

troduced into the cylinder to align the wheel for retraction purposes. The cam, under certain conditions, provides anti-shimmying properties.

As various designs of oleo units are produced, new features are often introduced to improve the energy absorption and rebound characteristics, or to reduce bearing friction, but generally speaking, the main features of the units are described in the foregoing.

The following information should be supplied to enable a design to be produced :—

(1) All-up weight of aircraft.
(2) Tail load.
(3) Number of units per machine.
(4) Vertical landing velocity.
(5) Number of landing wheels.
(6) Size and pressure of tyre.
(7) Maximum permissible working load on unit.
(8) Maximum strength load on unit.
(9) Maximum permissible piston travel.
(10) A line diagram of the chassis geometry.
(11) If available, a copy of the undercarriage specification.

Fig. 296.—Servicing Dowty tail-wheel unit on De Havilland Flamingo ; right hand points to hydraulic pressure-testing valve, and left to caster locking device for cross-wind landing.

Fig. 296A.—Rear wheel can be jacked without detaching cowling, and is removed by releasing two bolts.

Dowty Retracting Undercarriages

A Dowty arrangement offering many advantages incorporates what are now generally known as nutcracker struts. The function of a strut of this type is to provide an undercarriage member which forms a rigid bracing for the compression leg when the undercarriage is extended, and also embodies a complete retracting mechanism (other than the source of power) in a self-contained unit.

The undercarriage is designed for sideways retraction and the nutcracker strut forms the side bracing member. The retracting jack is carried inside the upper tube of this folding strut and the retracting effort is transmitted from the jack through a simple arrangement of links to the lower half of the folding member.

An undercarriage for rearward retraction incorporates another form of nutcracker strut in which the jack is a simple pin-jointed unit, anchored at its top end to a lug on the upper half of the folding member and at its lower end to a link pivoted near

the hinge pin. Jack reaction provides the required angular movement and also operates latch locks to hold the undercarriage in the extended position. This arrangement was designed to cope with the unusual undercarriage attachment points provided on the aircraft structure.

Dowty Retracting Tail Wheel Units

The modern high performance aeroplane is provided with a retracting tail wheel unit to reduce drag. In one form, a self-locking unit has a pin-jointed jack for retraction and lowering. In addition, this jack operates the locking plunger to hold the unit in the extended position for landing.

The operating principle is as follows :—The plunger, situated at the top of the unit, is attached to a sleeve sliding on the outside of the main shock absorber member, and the lower end of this sleeve is provided with a cross-pin engaging with curved slots in brackets. These brackets are rigidly attached to the crossshaft on which the unit rotates. The slots are so shaped that the first part of the operating jack movement withdraws the locking plunger from its socket on the aircraft structure without imparting rotational movement to the unit. After the plunger has been completely withdrawn, a moment is produced about the pivot, causing the pin to travel round in an arc, thus swinging the shock absorber into a horizontal position. In the reverse direction the first part of the jack travel swings the tail wheel into the landing position. Then a vertical extension of the slot allows the jack to travel still further and so force the locking plunger home. The oil supply to the jack is fed through a glanded swivel joint where the piston rod anchors to its brackets. This enables rigid pipes to be used and oil is conducted from the swivel joint to the cylinder, through passages provided in the piston rod.

Another type of retracting tail wheel unit incorporating levered suspension, embodies a lock operated by free travel of the retracting jack which in this instance is pin-jointed between a lever attached to the shock absorber body and a fitting on the aircraft structure.

Lockheed Hydraulic Operation

The design of Lockheed aircraft equipment is based on principles which have been established during many years of experience in hydraulic work of other kinds. The most characteristic is the use made of rubber which has well-defined mechanical properties which can be relied upon, but in turn demands working conditions of a special nature if these properties are to be maintained over long periods.

Since one of the greatest advantages of Lockheed equipment is the small amount of maintenance required, it is most necessary that these demands should be met.

Lockheed glands and flexible connections used in conjunction with Lockheed Fluid have stood the test of years, and it is with the great advantage of this knowledge that Lockheed aircraft equipment is made.

Hydraulic operation has at first sight two advantages; firstly, large loads can be dealt with easily, and secondly, a high velocity ratio can be obtained without complication, but there are other advantages such as low maintenance and ease of installation which are often of sufficient importance to bring within the scope of hydraulic equipment applications which do not fall into the two classes first mentioned.

Lockheed Aerodraulic and Airdraulic Equipment

Lockheed aircraft equipment is made under two registered trade names: " Aero draulic " and " Airdraulic." The former covers the purely hydraulic equipment for the retraction of undercarriages, the operation of flaps, etc., and the latter a range of Oleo Pneumatic Shock Absorber struts of all types. It is but a small step from these components to the design and manufacture of complete undercarriages, but the step, although small, is one of considerable importance.

In the past it has often been the case that details of the hydraulic system have only been considered when details of the retracting mechanism and undercarriage itself have been completed. In particular this is liable to result in peak loads much in excess of mean loads, and as a consequence the overall efficiency, taken as the proportion of work performed compared with work available, is low. Much saving of weight can be effected in all hydraulic equipment if this point receives attention.

The " Airdraulic " Shock Absorber Unit

The design of this strut is extremely novel and simple, and is based on the well-known principle of air cushioning combined with hydraulic damping. The main features are extreme simplicity of construction, each strut being essentially two simple

telescopic tubes of almost equal diameter, and very efficient energy absorption. These two points together provide a design which is not only the lightest possible but which also gives better shock-absorbing qualities than would otherwise be obtainable.

The top chamber of the strut contains fluid and the lower one contains compressed air, the floating piston serving to separate the fluid from the air. As the strut is compressed, the fluid in the chamber above the main piston is forced through the radial holes therein and thence through the central choke orifice in the flutter plate into the lower chamber above the floating piston, thereby forcing the floating piston to move downwards against the column of compressed air.

On the return stroke, the fluid returning from the lower fluid chamber to the upper chamber causes the flutter plate to seat against the radial holes in the main piston, leaving only the small central return choke orificc through which the fluid flows at a restricted speed into the upper chamber.

The strut is constructed mainly of light gauge high tensile steel tubes and light alloy internal parts, thus reducing its weight to a minimum.

The totally submerged choke orifice allows of an extremely high energy dissipation, and as a matter of interest official tests have shown this feature to be superior to the tapered needle type of choke orifice.

Fig. 297.—Retraction test of Lockheed landing legs on De Havilland Flamingo.

The floating piston holds the fluid column at all times in its correct position irrespective of the angle at which the strut is mounted, thus making it ideal for retractable undercarriages. Furthermore, since the fluid column can never come into direct contact with the air column, no aeration, emulsification or displacement of the fluid can take place after the first bump when an aircraft lands, so that the full efficiency of the strut is retained throughout the landing run.

The possibility of leakage is reduced to a minimum since the moving glands are entirely submerged and lubricated by the fluid column, and are protected from grit and dirt by the telescopic portion of the strut. Furthermore, the dangers resulting from such a leakage are also reduced to a minimum, as the fluid column is retained in its correct position by the floating piston for dissipation of energy should an air

leakage occur during flight. On the other hand, should a fluid leakage occur during flight, only a comparatively small amount of fluid can be lost before the floating piston is arrested by the lower end of the main piston, thereby relieving all pressure from the fluid column.

Attachment brackets and the like can conveniently be riveted or attached by any suitable method to the outer telescope tube in any position below the main piston, and suitable end fittings may be attached to the extremities of the strut. Furthermore, the telescopic tubes can conveniently be extended beyond the working portion of the strut, thus avoiding the necessity for extension pieces on long struts.

Owing to the fact that the main glands work against the bore of the outer tube instead of the outside of the inner tube, a much greater end load can be taken by a strut of a given diameter than is generally possible with other designs.

A special fluid has been developed for use with "Airdraulic" struts. This is known as Lockheed "Airdraulic" Fluid, and differs from "Aerodraulic" Fluid inasmuch as it is desirable to increase the lubricating value whilst it is not detrimental to increase the viscosity.

"Airdraulic" Fluid has been produced as the result of long experience, and the use of any substitutes will definitely reduce the efficiency of the strut and may cause ultimate failure.

Lockheed Axial Roller Bearing

One of the major problems associated with the design of cantilever undercarriages has been that of reducing friction between the telescopic members of the legs to prevent "sticking," harsh taxi-ing qualities, and the tendency of the aircraft to list to one side due to bad recovery of the shock absorbers. Hitherto plain telescopic bearings have been generally employed owing to the difficulty in housing suitable frictionless bearings; particular attention has had to be paid to the degree of inclination, and length of overlap of the telescopic members of such legs, and to the amount of offset of the wheels, to ensure satisfactory operation.

The Axial Roller Bearing fitted to "Airdraulic" Cantilever shock absorber legs has been designed both to improve the performance of the normal type of cantilever undercarriage, and to enable the undercarriage designer to take far greater liberties than have hitherto been permissible, without resorting to the use of heavy internally-sprung wheels of limited shock absorbing capacity. The bearing is extremely simple and efficient, and takes up no more room than a normal plain bush.

It is comprised of a number of close wound steel springs housed in radial slots in a tubular cage. The cage is fitted between the inner and outer telescopic members at the bottom end of the latter, and the spring rollers, which are normally straight, are curved to the contour of the inner and outer surfaces, and roll freely between them in their respective slots when relative movement takes place. Under load the rollers flex to an oval section, thereby increasing their contact area substantially in proportion with the loading, as compared with a ball which tends to embed itself and roll grooves along the bearing surfaces. This feature not only increases the life and load capacity of the bearing, but it also obviates the necessity for hardening the bearing surfaces.

The "Airdraulic" shock absorber strut lends itself particularly to the housing of this bearing, as the main sealing glands are contained in the plunger head instead of the usual housing at the bottom end of the outer member. During compression of the leg it will be seen that the roller cage travels up the outer telescopic member at half the speed of the inner member; at the end of the extension stroke it forms a stop between the plunger head and the bottom end of the outer member, and, being slotted, its flexibility absorbs any recoil shock loads which might otherwise be transmitted.

Lockheed Self-centring and Rotationally-damped "Airdraulic" Struts for Nose or Tail Wheels

These have been developed primarily for use as nose-struts in tricycle undercarriages and as tail-wheels in the normal form of undercarriage layout. They have all the advantages of simplicity and lightness common to other types of "Airdraulic" struts and, in addition, certain other properties which are essential to these particular applications. The design provides moderately free rotation when the rotation is slow—for example, when the machine is manœuvring on the ground—but resists rapid rotation and prevents "shimmy" when an aircraft is taking off or landing.

This is achieved by means of a rotary hydraulic damper which is also spring-loaded towards the central position and which has an unrestricted return to this position. This arrangement has the advantage that it is entirely self-contained within the normal

diameter of the strut and, being immersed in the operating fluid, requires no additional maintenance. External adjustment of the damping is provided within a limited range. All these features are fully patented, and obviate the necessity for such devices as external friction brakes or positive locking mechanisms.

Messier Oleo-pneumatic Shock Absorbers

All Messier shock absorbers are of the variable orifice type. It is not possible to obtain satisfactory energy absorption efficiency from a shock absorber with a single non-varying orifice area as the variations in the velocity of closure and other conditions under which the shock absorber works call for different orifice areas throughout its travel. Furthermore, an orifice which is adequate in size for landing under specified conditions will be too small to provide free and soft suspension on the ground when taxi-ing. A feature of Messier shock absorbers is the use of orifice regulating screws which can easily be adjusted at the factory or during taxi-ing trials without the complete dismantling of the shock absorber. The arrangement is such that closure and rebound can be adjusted independently. In the case of the old type of accessible struts fitted to aeroplanes with fixed undercarriages, adjustable orifice regulating screws are fitted for taxi-ing trials and these are adjusted by turning a handwheel until the optimum settings are found.

Messier Nose Wheels

Messier recommend a nose wheel with the following features :—

(*a*) Long shock absorber travel can be obtained by a straight oleo if ample length is available. In other cases, construction with a dashpot alongside an oleo-pneumatic shock absorber, or a fork carried on a deformable quadrilateral, can be used. Long travel is necessary on a nose wheel to avoid excessive loads on landing. Shorter travel during taxi-ing is preferable, to avoid excessive pitching. The " double " shock absorber solves this problem.

(*b*) Forward caster angles for military aircraft operating on soft aerodromes prevent easy castering, and backward angles for such machines give very much better manœuvrability. The increase in weight with this type of nose wheel is inevitable but worth while.

(*c*) Shimmy has to be eliminated to make a nose wheel practicable. The causes of shimmy are sufficiently understood to allow cures to be found. Simple friction dampers can be used on tail wheels with success but are too stiff on the normal nose wheel. Hydraulic dampers with special orifice characteristics are used on nose wheels ; these are internal vane or cam-operated plunger types.

(*d*) Light aircraft may well be steered from the rudder bar. Larger aircraft would have to be servo-controlled, and in practice it has been found that if caster is good (as it is with a backward raked fork) manœuvrability on the ground at speed is good also and steering is unnecessary.

(*e*) As the nose wheel is substantially loaded the addition of brakes is often worth while. This presents little difficulty.

(*f*) To prevent compass interference a retractable nose wheel may have to be non-magnetic. This is done by using non-ferrous metals, austenitic steels, K-Monel metal, Inconel for springs, etc., which involves very special machining technique and is certainly costly.

Turner Landing Gear

The Turner Manufacturing Co., Ltd., of Wolverhampton, have specialised for some considerable time in the design and manufacture of undercarriages, tail units and other components. Two main types of shock absorbers have been developed, the pneumatic type and oleo pneumatic. The pneumatic type employs air only as the working medium. This type is ideal for lighter aircraft where the laden and unladen conditions do not vary widely.

The oleo pneumatic type is illustrated in Fig. 300 and employs :—

(*a*) Air as the working medium during taxi-ing and in take-off.

(*b*) Oil to absorb the extra energy during landing.

This type is designed for the heavier range of aircraft where considerable variation exists between the laden and unladen weights. Any shock absorber with fixed characteristics cannot give equally good results with a wide range of conditions.

The operation of the shock absorber is as follows :—

The chamber A and annulus B are filled with oil to the level indicated, through the oil valve (1). The chamber C is charged with air pressure through the valve (2).

As the aircraft lands the piston moves up the cylinder and the air in chamber C is compressed. Simultaneously, oil in chamber A is throttled past the slots in the oil orifice sleeve (3) into the annulus B via the large holes in the piston. The slots of the orifice sleeve are previously determined in proper relation to the requirements of each aircraft. Each slot varies in length, consequently as the piston ring of the stationary piston passes over the orifice slots, the cross-sectional orifice area is reduced in stages providing a progressive retardation and absorption of the landing energy in addition to that obtained by compression of the air. On completion of the compression stroke, conditions illustrated in Fig. 300 are reached.

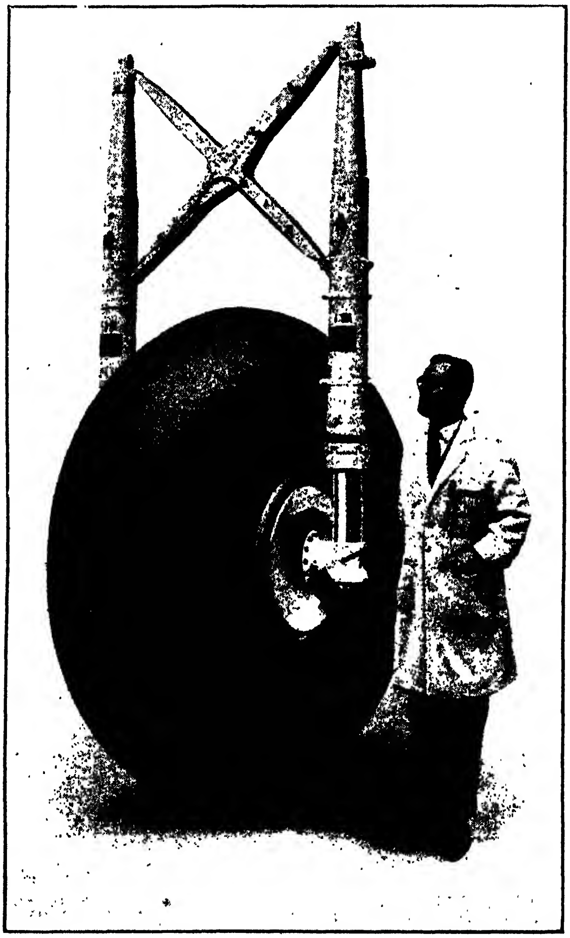


Fig. 298.—An undercarriage unit for the thirty-ton Stirling heavy bomber. When retracted, plastic doors and fairings partly enclose the unit. Each tyre weighs approximately 4 cwt.

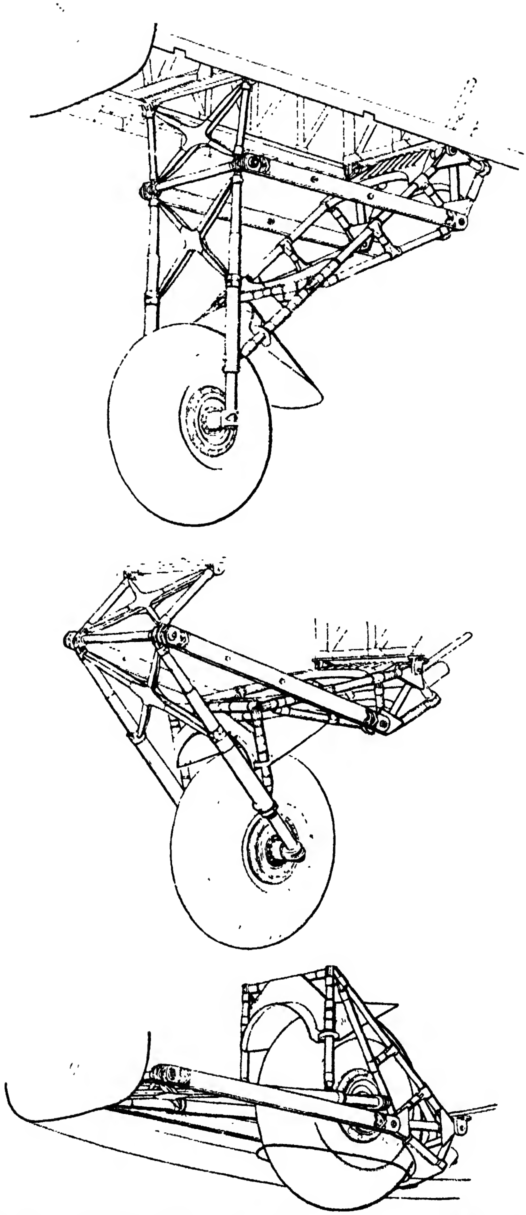


Fig. 299.—*Stages in the retraction of the Turner undercarriage, showing the simple manner in which a total length of* 13 *feet and weight of* 1,000 *lbs. is stowed away in the engine nacelle.*

On the return stroke of the piston and piston rod, oil in the annulus B is trapped due to the piston ring (4) being held against the face of piston. This oil has, therefore, to be throttled through the small orifice holes in the piston, providing the necessary damping action as the shock absorber extends.

Turner Undercarriage on Stirling

With an all-up weight exceeding thirty tons, the safety of the giant Short Stirling when taking off and landing depends largely on the undercarriage. Some idea of the massive proportions of this component may be gained from Fig. 298; including the 72 inch by 28 inch Dunlop wheels the overall height from ground to engine nacelle exceeds 13 feet when fully extended. The double joined design of the undercarriage unit is very unusual and, although at first sight it appears complicated, the construction is, actually, very simple (Fig. 299). When fully retracted, the unit is housed in the inboard engine nacelle, plastic doors and fairings protecting the projecting arc of the wheel.

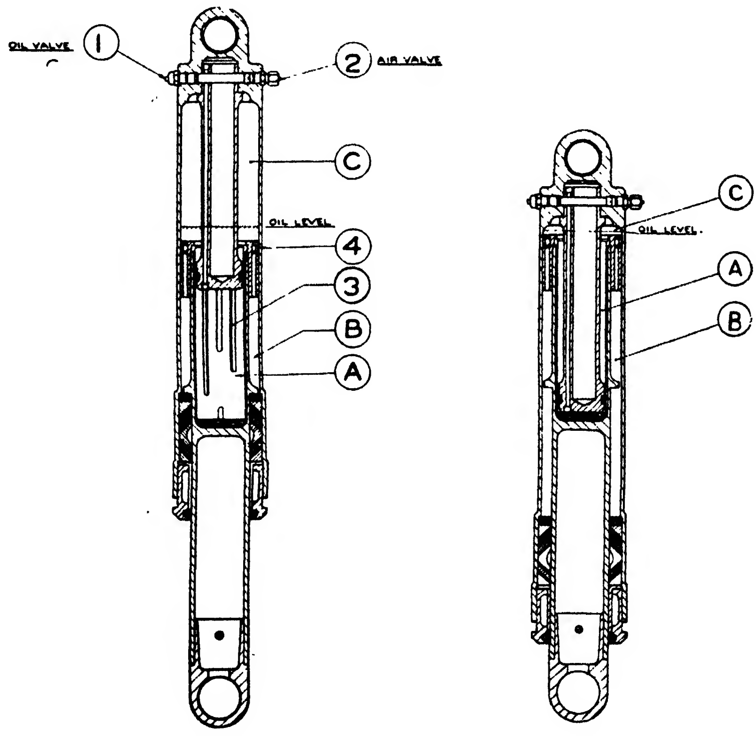


Fig. 300.—Turner oleo-pneumatic leg, extended and compressed.

The wheel is supported on an axle forming the lower member of a frame constructed from two oleo legs secured at the top by cruciform bracing. Because of the heavy weights and stresses involved, the oleo legs operate on the air-oil principle which allows sudden, heavy shocks to be taken with safety, providing for a maximum compression of 10 inches between the two extreme positions. Air is employed as the working medium when taxi-ing and taking off, the oil absorbing the extra energy present when landing, providing a cushioning effect.

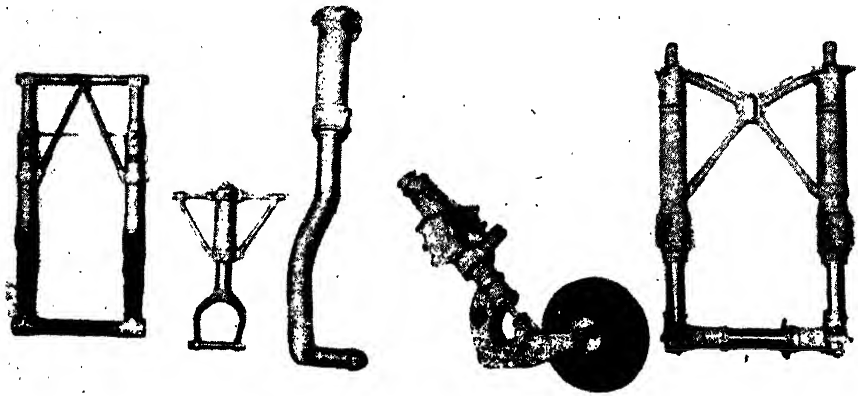


Fig. 301.—*A group of landing gear units manufactured by Turner Mfg. Co., Ltd. They are (left to right) Avro-Anson undercarriage, Fairey Battle tail unit and oleo leg, Blenheim tail unit, and on the right, a Blenheim undercarriage.*

AIRCRAFT WHEELS, BRAKES, AND TYRES

Avery Wheel and Brake

THE Avery wheel and brake has been designed to meet the essential requirements of aircraft construction, and has been the subject of several years' intensive development and research. It is in regular production, and standard units are being fitted to a number of this year's prototype machines.

Where landing wheels are to be incorporated in undercarriage equipment, they are supplied complete with the brake mechanism. The brake mechanism is not, of course, included in tail-wheel units.

The Avery unit represents a radical departure from existing designs in that the brake equipment is of the disc type. This development gives greatly increased braking efficiency and at the same time permits a considerable saving in weight, whilst the design of the wheel itself is notable for the ease and rapidity with which it can be dismantled and assembled when maintenance work has to be carried out.

It will be appreciated that the air resistance of the wheel is reduced to a minimum, i.e., the entire wheel with its brake mechanism is encircled within the section of the tyre, and there is no projecting brake drum. All the working parts are protected by dust and wet excluders, so that when the wheel is removed from the axle no foreign matter can possibly enter the bearings. An improved form of sealing device is provided which obviates the possibility of any grease from the bearings reaching the brake surfaces. The brake is fully progressive and stable in action, and is entirely free from a tendency to self-locking—a result which cannot be achieved with certainty where a shoe brake of the automobile type is employed. The elimination of the brake drum also reduces the weight of the unit considerably, since it is obvious that brake drums must be made very rigid and this requires a substantial section of material. As a result, the overall weight of the Avery landing wheel and brake is approximately 30% less than competitive wheels where the drum type of brake is incorporated.

As will be seen from the sectional drawing, the wheel is made as a casting, which is of light alloy and heat-treated to remove internal stresses. The hub centre is protected by an axle sleeve H, through which the axle is passed and to which it is clamped rigidly. The sleeve, with the outer hub flange and brake diaphragm D, is held against any tendency to rotate by means of the dowel holes J, which engage with dowels attached to the axle flange.

The outer brake casing C is attached to the wheel casting by the screws B and rotates with the wheel, a dust seal being made with the outer hub flange. Friction surfaces attached to the diaphragm D are sandwiched between the two braking surfaces of

the wheel, which are lined with hard detachable metallic facings. The normal clearance is approximately half-a-millimetre.

Situated within the two half diaphragms is a resilient expansible capsule of special material which is inert to oil or other fluid. The diaphragms have a certain degree of flexibility, and when pressure is applied to the brake system they are forced apart by the capsule, and in this way the friction surfaces make contact with the rotating linings of the wheel.

The wheel is carried on the hub sleeve by roller bearings, and on assembly the hub is packed with grease, which only requires to be replenished at long intervals. The wheel is held to the sleeve by means of the screwed nut G and lock washer E, both of which are secured against any possibility of rotation by the screws J. A felt seal is provided at F.

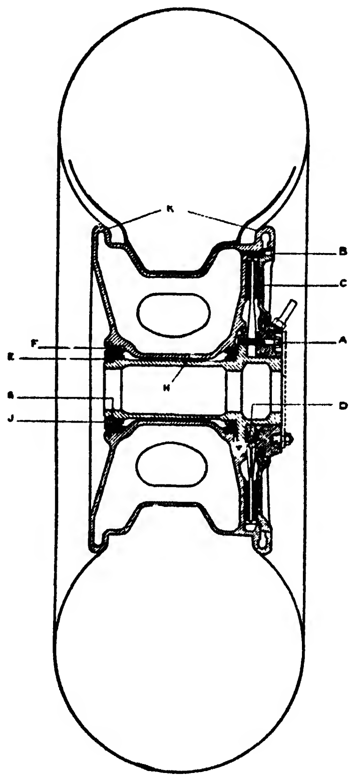


Fig. 302.—Diagram of Avery Wheel.

It will be obvious that with this form of brake there is no self-energising action, and for this reason the torque exerted by the brake is in direct proportion to the pressure applied to the capsule. There is no variation from the direct proportion throughout the torque range from zero to maximum.

The brake may be applied pneumatically or hydraulically through the nozzle which is carried by the outer hub flange. It is suitable for operation by any of the known types of control units.

In the disc type of brake the pressure on the friction surfaces is entirely uniform, and a high average loading is therefore possible with an even and low rate of wear. The care taken to exclude all dust and other foreign matter which may damage the brake

surfaces also contributes to the results obtained. This type of wheel has great structural strength.

Palmer Aero Tyres

It will be appreciated that very severe strains are imposed on an aeroplane tyre when, landing, especially on rough ground, and the excessive distortion to which the tyre is subjected as a result of the impact frequently causes a breakdown of the carcase commonly known as " concussion burst." The Palmer aero cover, however, is built to meet such conditions.

The chief design feature is the employment of only two layers of the special heavy gauge Palmer true cord as compared with four to sixteen layers which are necessary when using the light cord fabric of the motor tyre type.

This method of construction results in a much stronger carcase which is comparatively light and possesses amazing flexibility (even the largest tyre made can be easily folded double between the fingers). These qualities provide a carcase which does not " stone-bruise " and is therefore immune from concussion bursts.

Palmer Monodisk Wheels

In the efforts to reduce wheel weights for given loads the Palmer Tyre Ltd. has produced a type wheel which has been named the Monodisk. The Monodisk is a one-piece disc type wheel without the use of rivets, nuts, bolts, spokes or shields, completely eliminating wheel maintenance, while being machined as a unit its running truth is perfect. It can be supplied with either plain or anti-friction bearing. The inflation valve is housed under a flush-fitting rubber cap which preserves the clean lines of the wheel.

Streamline Monodisk—Wheel and Tyre

For high-speed machines where aero-dynamic efficiency is of such tremendous importance Palmer Tyre Ltd. have produced a fully streamlined Monodisk wheel and tyre in which the usual re-entrant angle between the tyre and wheel is non-existent.

Further, this has been achieved without the use of additional parts such as sponge rubber fillings or fairing shields, there being only three parts, the cover, tube and wheel. The unique cord construction tends naturally to produce a shape of streamline contour which only required a small modification to the walls of the cover in order to give a streamline exterior to the unit. To perfect the " lines " the hub cap has been sunk into the wheel and the aperture covered by a rubber cap which is retained flush with the surface of the wheel. A similar cap covers the opening for access to the inflation valve, while the lubricator nipple is also housed in a recess. This streamline form has been achieved with a very small increase in weight, while there is a valuable reduction in drag at least equal to that obtained by fitting spats.

Messier " Turbine " Wheels

With the old type of wheel the drum was surrounded by a mass of magnesium; the heat produced rapidly penetrated this mass with which the tube and the tyre are in direct contact. By careful distribution of the material and the use of cooling fins, this simple solution has enabled a satisfactory answer to be given to the braking problems of existing machines, but it is no longer adequate for new equipment.

With the " Turbine " wheel the magnesium rim is connected to the drum by thin spokes only, which greatly resist the direct transference of heat; furthermore, these spokes are shaped in the manner of fan blades inclined backwards and ensure a rapid circulation of air between drum and rim. The curvature of the spokes has the additional advantage of preventing excessive stress, due to temperature expansion.

Increase of Brake Effectiveness

It has been pointed out that it has become necessary to absorb more and more kinetic energy; the width of brake shoe as well as the shoe pressure has been increased. Finally a second brake drum has been added to each wheel, the two drums being fitted symmetrically on each side of the wheel, giving the maximum amount of brake surface.

The drums have been specially designed to give a good coefficient of friction at high temperatures, and without a tendency to score or " pick up "; furthermore, the dissipation of the brake heat allows much higher unit brake pressures to be used than previously.

Removal of Tyres

This operation has become rather intricate owing to the large tyres now in use. The manipulation of special levers can only be left in expert hands for the operation requires strength and accuracy to avoid tearing the rubber and fabric. The operation usually takes too long, and in practice it requires two men to carry it out.

The new flat rimmed wheels are in two parts. To remove the tyre and tube a dozen nuts are undone, allowing one rim to be removed.

Messier Brake Control System

In the Messier brake system, air and hydraulic pressure are used in conjunction to the best advantage. In the usual system, low-pressure air from a bottle is controlled by the brake valve and differential distributor, with ease and precision, and is transformed into high oil pressure through a relay and sent to the brake cylinders.

This system is sensitive to defective bleeding, air locks, and slight leaks, which may mean that the pilot has to make successive brake applications to compensate for such losses.

To avoid this defect a new system has been developed. It is completely insensitive to defective bleeding or small leaks as the volume of oil under pressure—the volume of the accumulator—is many hundreds of times greater than the volume of the brake cylinders.

Two circuits are possible :—

(*a*) A circuit using compressed air control relayed to the oil system. This circuit is in use on large modern aeroplanes.

(*b*) A newly developed circuit, completely hydraulic, and eliminating compressed air from the aeroplane.

Palmer Aero Wheel Brake

The unit consists of only two parts, i.e., brake frame and the brake liner. Exceedingly light in weight, but giving exceptionally strong braking effort, the brake comprises an annular expansion chamber to which is attached a complete ring of brake blocks, which, when the brake is in operation, are forced into frictional contact with the brake drum. The pressure required for even a considerable braking effort is small owing to the fact that there is nearly 100% contact between the brake blocks and the drum, and as the pressure exerted is uniform over the whole area, the drum itself can be much lighter than is normally employed with the ordinary shoe type brake, and wear on the brake blocks is practically nil.

The brake drum support is machined perfectly circular and concentric with the wheel before the drum is placed into position, so that distortion of the drum during the process of wheel building and trueing is impossible, and if small distortions should occur, as the result of shock, while in use, the efficiency of the brake is unimpared as the expansion chamber to which the brake blocks are attached " breathes " in sympathy with any small irregularities in the drum.

The brake blocks can be renewed by the simple operation of lifting out the brake liner and dropping another in its place. For this, no tools are required other than the ordinary tyre lever. The brakes for hydraulic operation have an additional nozzle for priming, while in the air operated type there is only one nozzle.

Palmer Brake Controls

Operation of the Palmer brake may be either by pneumatic or hydraulic pressure, and in each case there are numerous optional methods of control. Generally speaking, for the small types of aircraft the hydraulic system has been found more suitable, while on the large machines, air is generally adopted, especially as it is usually already available for engine starting purposes. The principal methods of operation are :— Hydraulic or pneumatic, foot operated individual control to each wheel. Pneumatic, hand operated individual control to each wheel. Hydraulic or pneumatic, hand with rudder bar differential operation. Hydraulic or pneumatic dual control (for training machines).

Variations of the above operations can be supplied to suit special requirements.

A common feature throughout Palmer brake systems is the absence of mechanically moving parts, which makes routine maintenance practically negligible.

In all cases pressure is conveyed to the brakes through a small pipe line of either aluminium, copper or rubber, as desired. These are made in two sizes : $\frac{9}{32}$ inch O.D. metal pipe for hydraulic systems ; and $\frac{3}{16}$ inch O.D. for pneumatic systems, with rubber hose in sizes to correspond. The Palmer rubber hose is made in two

types, plain and metal braided, the latter for heavy duty. No other type is suitable, and if used is bound to cause trouble. This special Palmer hose is reinforced with many layers of cotton fabric to withstand the working pressure, while the rubber is specially compounded to resist action by the fluid used in hydraulic operation; further, the internal dimensions are such that it gives a tight fit over their standard metal pipe lines and into the metal unions which are made in sizes to correspond.

Connections between the metal pipe and hose are made with special duralumin unions. These are very light and robust and can be easily disconnected without damage. Their simple three-piece construction consists of a ferrule which grips the rubber hose by the action of screwing together the union.

Palmer Brake Control (Hydraulic Type)

As an example of Palmer brake control of the hydraulic type, No. 726 control has been designed to give straight braking by operation of a hand lever mounted on the control column or wheel, as the case may be, with differential action for steering by interconnection with the rudder bar which is used in the normal way. Thus the pilot has full control of the brakes without in any way interfering with his normal hold or use of the throttle, control column, and rudder bar.

Installation

The control consists of a single unit which can be mounted on the aircraft in any convenient position where it can be coupled to the rudder bar or mechanism thereof through a link or rod, preferably adjustable in length. A Bowden cable passes from the unit up the control column to the operating lever. The hydraulic supply is drawn from the existing system on the aircraft.

There are four connections on the control, the two centre ones being supply and exhaust—the latter being that on the rear end nearest the differential lever—the two outer connections coupling to the port and starboard brakes.

Branch pipe lines are taken off through " T " pieces from the supply and brake lines to a triple pressure gauge which shows the functioning of the system and indicates the location and nature of any irregularities which may arise.

Features

The principle features of this control are :—

(1) A simple adjustment of pressure to brakes, with definite limitation to a predetermined figure.
(2) Impossibility of any failure allowing excessive pressure to reach the brakes.
(3) Constant pressure in the brakes irrespective of variations in the supply pressure.
(4) Light loading of the hand control which obviates cable stretch.
(5) Indefinite parking without leakage.
(6) Full braking for all purposes independent of engine.
(7) Damping action on rudder during parked condition.

The control is usually associated with an accumulator in the main hydraulic system which provides for a limited number of brake applications after discontinuance of the power supply. It is also usual to associate the control with the undercarriage emergency hand pump for recharging the accumulator.

The pilots' operating lever should be provided with a simple adjustable screw stop to control the lever movement, thus limiting the maximum brake pressure. The pilots' operating lever should also be provided with a parking catch for locking it in the " on " position.

Description

The control itself consists of two portions. the main body integral with base and the end casting. Each consists of three cylinders in the form of a triangle, the cylinder housing the main valve forming the apex. Each of the three cylinders in the end casting houses an inlet valve which is mounted in line with its exhaust valve and operated by it through the medium of a tappet.

The lever protruding from the rear of the control, when coupled to the rudder mechanism, provides a reduction in pressure in one or other brake, proportional to the amount of rudder applied, whilst the pressure in the opposite brake is maintained to the extent of its application.

DUNLOP AEROPLANE TYRES

The Functions of the Aeroplane Tyre

THE earliest aeroplanes used tyre and wheel equipment borrowed from existing bicycles or motor cars. Such equipment was of a makeshift type, but was used with reasonable success under conditions for which it was never designed. To-day ranges of aeroplane tyres are available, designed specifically for use on the modern aircraft and specially fitted to deal with varying conditions of operation.

The chief funcitons of the aeroplane tyre are the supporting and the cushioning of the machine during take off, landing, taxi-ing and standing. At the same time the tyre must transmit the stresses produced by the brakes of the machine, and must resist treadwear and accidental damage. The main demand, however, is for cushioning, and a large contact area between tyre and ground is essential, especially on soft aerodrome surfaces.

A great deal depends on the tyres of the aircraft during taking off and landing. At the same time it should be recognised that once the machine is in the air the tyres and wheels become useless and superfluous and remain so for most of the flying life of the aircraft. It follows, therefore, that the tyre equipment has been pared down to minimum size and weight by the designs of the aircraft, and that it is left with the minimum factor of safety, but with a factor which is completely adequate as long as it is properly maintained, and operated with reasonable care by the pilot.

Take-off conditions are severe, the aircraft carrying its maximum load and fuel. The load, however, becomes gradually airborne as the speed increases.

Landing conditions depend upon the skill of the pilot and the general conditions prevailing.

It cannot be sufficiently stressed that the conditions at the actual time of touch-down may be extremely severe. The stationary tyre and wheel unit, possessed of considerable inertia, is suddenly wiped over the ground at the touch-down speed, which is usually between 80–100 m.p.h., or higher on night operation, or on machines with tricycle undercarriages. The wheels are rapidly spun up to the running speed of the plane, but during this period there may be considerable slip between the tyres and the ground surface, and in the process the tyres may be badly abraded, especially when landing on prepared runways, unless the wheels are free to rotate and all unnecessary friction eliminated. The touch-down should be as light as possible, to ensure that there shall be a reasonable period of light contact during which the stationary tyres and wheels are spun up to the full speed before the full weight of the aircraft is imposed upon them. It is also important to ensure that the wheel brakes are completely "off," and that the wheels are free to rotate when the landing is made, in order to avoid additional drag when spinning the wheels up to speed.

From tests which have been carried out it has been proved that if the above elementary precautions are taken there is nothing to be gained by the provision of apparatus for spinning-up wheels before touch-down. The advantages of such gear are more than outweighed by their disadvantages.

The Different Ranges of Covers

Aeroplane tyres are made in a wide variety of sizes and types to meet the requirements of aircraft designers, who are generally interested in equipment to carry a maximum load with maximum safety and cushioning, but with a minimum weight and minimum size of tyre and wheel.

A wide range of different sizes is made, with more than one type of construction in many sizes. For the sake of convenience this multiplicity of tyres can be grouped together under a few broad headings, descriptive of the general lines upon which each group is planned.

Thus we may divide tyres into three categories :

(*a*) main landing wheel or undercarriage sizes ;
(*b*) tail wheel sizes ;
(*c*) nose and tail wheel sizes.

Each of these main groups may be subdivided as follows :—

(a) Main Undercarriage Sizes

(i) *Intermediate Range.*—This is designed to operate at 33⅓% deflection and at 35 lbs. inflation pressure, and is in general use to-day. The "intermediate" description fixes the position of the range in the general scheme of aeroplane tyre design, and

it is, in fact, " intermediate " in proportions between the original small section large rim diameter, high-pressure tyres, and the large section " wheel-less " type, fitting on a wheel of such small diameter as to be only a hub, which was originally developed in America.

Its small overall diameter makes the Intermediate range particularly suitable for use on retractable undercarriages where space is limited. The wheel and tyre assembly is also lighter for a given load carrying capacity than was the earlier High Pressure tyre.

(ii) *Original High Pressure Range.*—As already mentioned, this was the original range and the name is sufficient description. A few sizes of this range are still employed on current aircraft, usually associated with fixed undercarriages. They are made in Standard and Heavy types, the latter being of strengthened construction to work at higher inflation pressures and to carry heavier loads. The use of such equipment, with its high contact pressure and small contact area between the tyre and the ground, is not satisfactory on aerodromes with soft surfaces.

Developed from the High Pressure range we have the " Streamline " tyres, which are specially designed to reduce air drag on non retractable undercarriages. Here the tyre walls are faired into the edge of the rim, which is itself covered with a fairing disc. This simplification of the outer surface of the tyre and wheel assembly produces a material reduction in drag as compared with standard types. A similar range of American origin is in existence, as is also the " Smooth Contour " type, which is midway between the normal high pressure and the streamline. These are being produced by British manufacturers in a few sizes for replacement purposes.

There is no standardisation between British and American sizes generally, and the two ranges are not interchangeable with one another.

(iii) A range of tyres for heavy and light aircraft is now under consideration in which the design is based on an inflation pressure (to be regarded as maximum) of 50 lbs. per sq. inch. These tyres are of squat section and have larger rim diameters than the Intermediate type and allow the inclusion of brakes of improved capacity. The overall dimensions of these tyres compare favourably with those of the Intermediate range and load/weight characteristics at the higher pressures offer advantages over the latter range at the lower design pressures.

(b) Tail Wheels

(i) *Wheel-less Range.*—These consist of small-diameter hubs carrying large-section tyres, and the size and weight of tyre for a given load capacity and a given cushioning capacity are reduced to a minimum.

(ii) *High Pressure Range.*—These correspond to the main landing wheel group of the same name, as described.

(c) Nose and Tail Wheel Range

This is a new group of sizes, of recent introduction, and is midway between the Wheel-less and the Intermediate range. They are designed for higher loadings and pressures necessary to accommodate the increased loading reactions. The range is used on tail wheels and on the front wheels of tricycle landing-gear.

The treads and side-walls of all tail wheel and nose and tail wheel tyres are made of a special rubber compound with a relatively high electrical conductivity. This results in a very rapid earthing of any static charge which the aircraft may have accumulated in flight. The discharge is almost instantaneous and is completed in the first thousandth of a second after the tail wheel touches the ground. The discharge of static electricity in the presence of petrol is particularly dangerous. The use of an electrically conducting tail wheel helps to remove this danger by ensuring that the point of discharge is well away from the petrol tanks. It also acts as a safety measure to prevent ground crews from receiving shocks on touching aircraft that have landed in a charged condition.

The current specifications require that the resistance of an electrically conducting tail wheel shall not exceed 10 megohms, measured between the aircraft and the ground, at any time during the life of the tyre. In practice it is found that the resistance of an electrically conducting tyre may lie between an initial figure of a few hundred ohms, and about one megohm at the end of its service life.

The resistance of the tail wheel equipment of an aircraft may be measured or checked with a megohm-meter or " Megger " tester, such as is used in checking faults in general electrical installations. The resistance must be measured between the aircraft bonding-terminal and a metal earthing-spike driven into the ground. The aircraft should not be standing on bitumen, asphalte, or other highly non-conducting

surfaces. The resulting measurement gives the resistance of the tyre, the ground contact, and the ground itself. In doubtful instances, the resistance of the tyre itself should be determined, by rolling it on to a metal plate, free from grease or corrosion, moistened with water, and then checking the resistance between this plate and the bonding-terminal of the aircraft with the "Megger" tester.

Tread Patterns

Some aeroplane tyres are supplied with broken patterned treads. Note, by the way, that the word "tread" is applied to the protective outer-layer of abrasion-resisting rubber, irrespective of whether it is plain and smooth, or whether it is moulded into a broken pattern in an engraved mould. Such patterns are generally much shallower in proportion to the size of the tyre than are the patterns of car or truck tyres. Their use on aeroplane equipment began with the increasing landing speeds and the introduction of braked wheels and artificial runways. The following broad lines sum up their usefulness.

Patterned tyres offer little advantage on grass or heavy ground, as the pattern cannot be made deep enough to secure a grip on such surfaces. On dry concrete, or tarmac, it is well known from ordinary motoring experience that the larger the surface area in contact with the rough surface of the track, the better the retardation. Just as the bald car tyre gives the best grip on such surfaces, so is the plain treaded aeroplane tyre actually better than one with a broken pattern. The patterned tyre does, however, score on wet smooth runways of tarmac or concrete. Here the edges of the pattern really come into play, and the lubricating film of water is scraped or squeezed off, to escape along the grooves of the pattern, so that a better grip and shorter pull-up are secured.

The patterned tyre prevents extended scoring or cutting on loose surfaces, as the pattern edges deflect loose matter and tend to localise the damage, while the fact that when the tyre is inflated practically all the stretching takes place in the grooves of the pattern, leaving the surfaces of the studs under little tension, means that liability to cutting is largely minimised.

A recent development is the twin-contact tyre, in which the load is carried on two isolated ribs on the shoulders of the tyre, corresponding to the edges of the tread of a normal tyre. This has been introduced and tested in conjunction with the Royal Aircraft Establishment, in order to counteract shimmy. The underlying principle is to replace the small elliptical contact area of the conventional tyre (about which it pivots in shimmy fairly freely), by twin contact areas of elongated shape, displaced some distance laterally from the normal centre of the tyre contact, and offering considerable resistance to pivoting movements about that centre, such as are involved in shimmy.

The characteristics of the twin-contact tyre are such as to require regular attention to maintenance if fatigue failures of the wall of the cover are to be avoided. When this tyre is fitted, any damping devices in the strut or undercarriage should be rendered inoperative.

In the case of the wheel-less tyres it is possible to produce a twin-contact tyre the dimensions of which are more or less comparable with the round-tread. This is due to the circular section of the wheel-less tyre which allows the length of the wall to be shortened and a more squat tyre built with the twin-contact tread on it. This procedure, of course, entails a special tube of reduced sectional size. In the Nose-wheel and rail-wheel range, in which the tyre sections are already squat, such a procedure cannot be adopted and the tread is added as a superstructure to the existing cover, which still takes the same tube.

From the foregoing it will be seen that with the wheel-less type of tyre a twin-contact cover can usually be accommodated without alterations to the fork, but with the Nose- and Tail-wheel range fork changes are nearly always necessary.

Tubes

As already mentioned, the tube is the real air container. In order to function properly it must be a correct and accurate fit to the inside of the cover and the rim surface of the wheel. The modern tube is designed to give a perfect fit without creasing, or without undue stretching of any part. A large number of sizes is produced by moulding, and when manufacture is complete they consist virtually of one piece of vulcanised rubber, with no perceptible joint or inequality or weakness. This does not apply at present to some of the smaller output sizes, and, especially in some of the very largest types, the tube will be seen to consist of several separate segments, carefully built up together.

The rubber compound used for aeroplane tubes has the following special characteristics: (i) low weight, (ii) flexibility, (iii) low porosity, and (iv) resistance to ageing and heat.

The tube is marked with the size of the cover to which it belongs, and each is peculiar to its particular size of cover and not interchangeable with any other size.

A special tube with a reinforced base is available providing increased resistance to deterioration under conditions involving high braking efficiency.

Excessive heat generated by braking tends to cause thinning of the tube rubber at the base. To counteract this, the tube is reinforced by the addition of heat resistant ingredients in the rubber mix itself which are localised at and thicken the base. In some well-base sizes protection is offered by simply thickening the rubber at the base of the tube.

Wheels

For clarity the following brief note on types is given here, in order that the terms used in subsequent description may be understood.

There are two main types of tyre and wheel fitment:

(*a*) *Well-base.*—In the original High Pressure range, where rim diameters are large and tyre sections relatively small, and in some of the intermediate sizes, the tyres are fitted to wheels of the familiar well-base or drop-centre type, as used on bicycles, motor-cycles and cars. Here the wheel is in one piece and the rim has a " well " or depression in it, into which the beads of the cover are forced during the fitting operation so that the part of the bead diametrically opposite may be fitted over the rim edge. In this way an inextensible tyre bead is fitted to a wheel which is larger in outer rim diameter than the bead itself.

(*b*) *Flat base.*—In the Intermediate and various Tail wheel ranges, as the tyre section gets larger and the rim diameter smaller, the difficulty of fitting to a well-base wheel becomes greater and recourse is had to a two-piece wheel with a flat-base rim. Some of these are made with a detachable flange and locking-ring, while in other cases the wheel is split into halves which are bolted together.

Some of the Wheel-less (hub-mounted) range of tyres are fitted to hubs which have decagonal bead seating surfaces with flats on them instead of the usual circular form This design is intended to lock the tyre to the wheel and to eliminate creep of the tyre on the rim. In other instances a key is moulded on the tyre bead corresponding to a recess in the bead seat of the wheel, and the construction applies to nearly all single-piece well-base wheels.

All that need be said here of these devices is that it is imperative to ensure that such covers shall always be fitted to the correct wheels.

Puncture Sealing Liquid

A special Puncture-sealing liquid is supplied for use overseas where camel-thorn or other puncture producing material may be encountered on landing grounds. It consists of a stabilised rubber latex containing fibrous material and suspended solids. This is introduced into the inner tube of the tyre, in sufficient quantity liberally to cover the crown of the tube as the wheel revolves. When a puncture occurs, the air pressure forces the puncture sealing liquid into the hole in tube and cover, and the hole becomes bridged by the fibrous matter, upon which the suspended solid material builds up. Finally the rubber latex forms a film of new tough rubber, which binds the obstruction together and ensures that it effectively seals the hole.

The method of use is as follows:

1. Stir or shake the liquid well before using. Stir again immediately before introducing into the tube.
2. Jack up the wheel, if already on an aircraft.
3. Deflate the tyre and remove valve insert.
4. Turn wheel to bring valve to the lowest position.
5. Introduce Puncture Sealing Liquid by means of a special charging gun (Dunlop Part No. B9/455).
6. Replace valve insert and inflate the tyre.

It should be emphasised that the use of the puncture sealing liquid is only to eliminate delays and dangers in service resulting from numerous punctures. Tyres containing it should be serviced and maintained with just the same care as those without it, and on any sign of partial deflation, such as takes place while the puncture sealing liquid is building up a seal in a punctured cover, the tyre in question should be removed at

the earliest possible opportunity, and the tube properly patched. The damaged cover should also be repaired before any extension of the damage has a chance to develop.

It is sometimes found that the puncture sealing liquid seals up the valve of the tube. When this occurs the valve insert should be removed and replaced by a new one. Supplies of spare inserts should be kept for this purpose where puncture sealing liquid is in use.

Loads and Inflation Pressures

Each size of aeroplane tyre has a definite load carrying capacity, which is determined by the volume of air which it contains.

The manner in which the weight of the aircraft is distributed between the wheels can be determined approximately by calculation. Where hydraulic jacks are available and are fitted with pressure gauges, the load can be determined accurately and immediately from the pressure required to jack up the aircraft, and the tyre pressures adjusted accordingly. Where platform scales, as used for centre of gravity determinations, are available they can be used to determine the loading on each tyre.

Therefore each airfield is provided with information preferably in wall chart form indicating in precise detail the tyre sizes, inflation pressures and tyre maintenance procedure applicable to the particular type or types of aircraft located there.

These provide in concise form all the necessary date for the regular servicing of tyres on aircraft, whether operational, at dispersal points, or in hangars.

They layout of such charted instructions is kept simple and direct to ensure the consistent carrying out of routine tyre servicing duties on the part of the personnel responsible.

Appropriate provision is to be made for any necessary revisions of charted instructions as may apply from time to time according to possible load variations or other relative conditions.

(*a*) *Inflation and Pressure Checking.*

The adequate servicing of the tyre equipment or aircraft is of the greatest importance and cannot be too strongly recommended. No one attempts to fly without fuel because it has been proved that it cannot be done successfully. Topping-up the inflation pressure of tyre equipment is quite as important as filling the fuel tanks, but, unfortunately, failure to do so does not make itself felt in so emphatic a way. It is possible to go on flying a plane repeatedly without attending to tyres at all. The final result is usually that the pressure drops so low that the cover creeps on the rim and the valve is torn out of the tube. This may result in serious damage to the aircraft and danger to its occupants, which risk may be avoided by a regular servicing.

The tyre pressures of all aircraft in use should be tested at each daily inspection and topped up to the specified pressure when necessary. Those of stored aircraft should be tested weekly and topped up if necessary. Stored aircraft, except when on jacks with wheels retracted, should be moved once a week so that the weight does not rest continuously on one part of the tyre. Oilskin covers should always be used over the wheels. The air used for inflation should be filtered and free from oily vapour or foreign matter, otherwise damage will occur to the red rubber washer of the valve insert, together with deterioration of the tube rubber.

Pneumatic servicing trolley units should be available for inflating tyres on aircraft dispersed at large distances from the main hangars. Care must be taken to ensure that the maximum pressure in the air cylinder is regulated by the correct use of the reduction valves provided. There is danger to personnel and equipment if airbottles or pneumatic systems are used for inflation, in which the pressure exceeds the maximum pressure required by the tyre, unless reduction valves are used.

Visual inspection of tyres to see if they are sufficiently inflated is completely unreliable. Where deflection lines are provided on the shoulders of the tread, indicating the normal width of contact, as on American sizes, these may be used as a rough guide, but pressures should still be checked with a gauge. Pressure checking must be carried out by means of a pocket gauge of pencil-type, such as the Dunlop No. 7. Fig. 303. This gauge can be used for all types of aircraft, except those on which the largest tyre sizes are fitted, e.g., 22.00-18, 24.00-19, 26.00-26, 26.50-21, which are fitted with large capacity valves with wide orifices for quick inflation and deflation. A special gauge, Dunlop No. 12, or Schrader No. 9715, must be used for these sizes. Fig. 303.

Gauges should be handled with care and should be preserved from denting or other damage, and should be kept dry and free from dirt, oil, or grease. All tyre pressure gauges should be checked once a month against a master gauge.

Valves fitted with " Dublchek " caps should be inflated and checked for pressure without removing the cap, which should be kept screwed down hard with pliers.

(*b*) *Periodical Inspection of Covers—Classification for Repair and Scrap.*
The tyres on all aircraft are to be examined superficially at each daily inspection. Stones and flints embedded in the tread are to be removed, the cuts examined, and action taken as detailed below. Any large fall in inflation pressure, not amounting to total deflation, is to be suspected and the cover examined for damage by foreign objects such as stones or nails picked up on the aerodrome.

At times to be determined by the service of the aircraft, and as laid down in the maintenance schedules, the tyre equipment is to be stripped from the wheels and carefully examined, both internally and externally. The following are the main points to be noted in such examinations, or at any other times when equipment is being scrutinised.

(*c*) *Condition of Tread and Walls.*
Covers worn to the white indicator strip should be removed at once. Damage by cutting or scoring by foreign matter on landing grounds or runways is best seen while the cover is still inflated on its wheel. Any extensive cuts should be opened with a blunt instrument, so as to reveal the depth of the damage. Open cuts extending to the cotton foundation of the tyre permit the entry of water and lead to rotting of the tyre fabric.

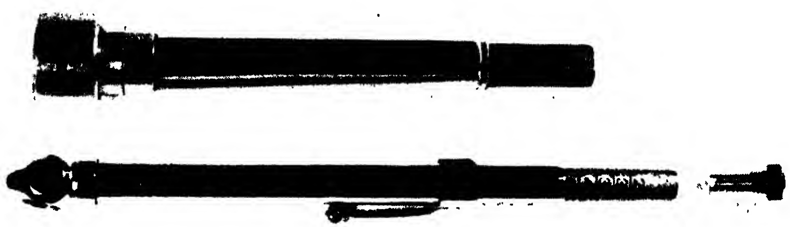


Fig. 303.—*Dunlop No. 7 pocket type testing gauge, below, and Dunlop No.* 12 *large capacity gauge, above.*

Deformation of the walls or tread, in the form of hollows or bulges, indicates partial fracture of the casing. Such tyres should be removed immediately as such damage rapidly develops into a burst. If a concussion fracture is found on one tyre of an aircraft it is a wise precaution to strip the fellow tyre for examination. A spongy appearance of the tread or wall rubber is due to softening of the rubber by contact with solvents such as engine oil, petrol, hydraulic brake fluid or glycol.

Condition of Beads

Examine the tyre walls just above the rim, for any signs of rim chafing, produced by rippling of the tyre against the rim edge as it runs, under the conditions of relatively large deflection which obtain. Such chafing is aggravated by under-inflation, and tail-wheel shimmy.

In severe forms it is visible on the inflated cover, but it will usually be detected at an earlier stage during, the periodical removal of tyres for inspection. Excessive brake heat can produce bead break-up which is unmistakable and is often accompanied by exposure of the steel beadwires.

Condition of Casing

When a cover is removed, either for the routine inspection of for the repair of puncture or other damage, the inside should be examined for casing fractures, due to concussion or fatigue. With the larger covers it will be found best to roll the tyre along the floor and to inspect the area which is flattened out by contact with the ground, where fractures tend to open out and to make themselves more visible.

Condition of Aircraft

It may be stressed that the performance of aeroplane tyres is profoundly affected by the general mechanical condition of the aircraft, and that the best service will only be obtained from the tyres of an aircraft if the condition of hubs, oleo legs, and other working parts is kept well maintained and well lubricated.

The bad effect of wheel shimmy or wobble on tail wheel or nose wheel tyres must also be noted. Every effort should be made to reduce such wobble to a minimum, by use of the appropriate damping or locking devices, where provided, and by maintaining correct tyre pressure. The use of twin contact tyres has already been mentioned.

Misalignment of the wheels of the aircraft increases the rate of tread wear and also increases the strain on the casings and the beads of the tyres. Aircraft should be checked periodically to ensure that the camber (leaning of wheels to the vertical), and the toe-in or toe-out are in line with the constructors' recommendations, noting from the instruction book if the tail is to be up or down.

Operating Conditions and Tyre Performance

(i) *Tread Wear.*—The growing use of prepared runways of concrete or tarmac has focussed attention on aeroplane tyre wear or damage, especially on main landing wheels where camber or toe-in or toe-out is present, and on nose- and tail-wheels. Tyres are therefore being produced in the smaller sizes with increased tread thickness to meet this increased wear.

Aircraft having cambered wheels tend to produce one-sided tyre wear. To conserve rubber and to even-up the wear of the tyre periodical reversals of such tyres should be made. In the case of well-base tyres having bead keys it has been proved by experiment that these may safely be cut off so that the tyre may be reversed, providing that inflation pressures are kept up to the recommended level.

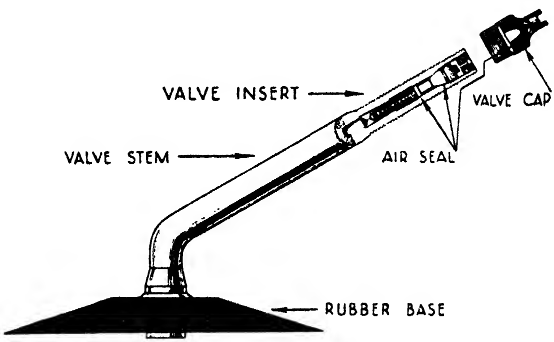


Fig. 304.—*Arrangement of valve stem in Dunlop Aero tyres.*

A strip of white rubber is now fitted to many tyres below the tread, so as to give a readily visible warning when the tread is worn through. Such covers are identifiable by a white marking in the code panel.

The following recommendations are made for reducing tyre wear and tear when ground manœuvring:

(*a*) Avoid sharp ridges such as runway edges.
(*b*) Avoid sharp turns.
(*c*) See that the tail wheel lock, if fitted, is unlocked when ground manœuvring.
(*d*) When ground manœuvring tricycles, use any release pins which may control the castoring angle of the nose wheel. If the nose wheel is not in straight-ahead position the turn should be started in the direction in which the nose wheel is pointing.

Shimmy on nose or tail wheels should be reduced by correct maintenance of any dampers fitted, or by the use of twin contact tyres. Friction dampers should be correctly adjusted and hydraulic dampers correctly filled and inflated where necessary.

(ii) *Use of Brakes.*—Everything possible should be done to reduce the unnecessary wear of tyres, by reducing the use of brakes and by the avoidance of harsh touching-

down, as already described. If brakes are binding or are applied before touch-down tyre life is greatly reduced. Great care should be taken in making turns, to avoid locking the inside wheel, which should always be allowed to roll on a radius of at least three yards.

(iii) *Tyre Creep.*—Under extreme conditions of service, involving low inflation pressures, heavy braking, high loads, and shimmy of tail or nose wheels, aeroplane covers can be made to creep on their rims, leading in the end to tearing out or fracture of the valve of the tube. As a check on creep a white radial line should be painted across the wall of the cover and the rim. This should be 1½ inches wide on all main landing wheels and 1 inch wide on all wheel-less and nose- tail-wheel covers.

Some covers have datum arrows moulded radially on the side-walls of intermediate and tail-wheel covers at the fitting line. These can be used as markers, a straight edge being placed across the cover and the rim edge marked with a scriber in line with the arrows. The tyre itself should not be marked with scores for this purpose as this leads to cracking of the wall rubber.

The position of these arrows with respect to the marks on the rim should be checked at the daily inspection and in instances where outside influences render creep troublesome it may be necessary to check up at even more frequent intervals. The permissible creep, including " settling down " of the cover on the rim, is the width of the white painted line, in each case. When creep is detected the valve should be examined. If it is still free the assembly may be left to run on. If the valve is hard against the side of the valve-hole or slot, or if creep has taken place to the extent of the width of the white line, then the cover should be stripped and the tube examined for valve damage or incipient tearing-out at the valve base.

The cover should then be refitted and precautions should be taken to avoid recurrence of the creep by keeping up the inflation pressures and by careful avoidance of unnecessary braking of main landing wheels or shimmy of tail wheels.

(iv) *Sweeping and Scavenging of Runways.*—Adequate provision should be made for reasonable maintenance work, not only on the aircraft and its tyre equipment, but also on the aerodromes themselves.

Runways should be kept swept of concrete debris and stones, particularly of such large fragments as get carried across from the edges of the runways by aircraft landing crosswise on them under the exigencies of wind or space. This sweeping should also extend to perimeter roads, aprons, the floors of hangars, and in fact any surface over which aircraft are moved in the course of their normal operation.

Special attention should be given to tyres used on temporary or makeshift aerodromes, on grass or muddy terrains, where expanded-metal mats are used to prevent wheel-sinkage in the mud. Serious cutting or scoring, and other damage of this type, can result from contact between the tyres and the holding-down pegs which have worked loose, or with the edges or surfaces of such matting. Such damage should be specially looked for in the daily inspection of the tyres of aircraft operated under such conditions.

(v) *Use of Covers over Tyres and Wheels.*—Protective covers should always be placed over the tyres and wheels when aircraft are parked for any appreciable period, or when any engine maintenance or draining of fluid systems is to be carried out. This not only prevents damage to the treads and walls of the tyres, but it also makes it impossible for oil or other liquid to find its way on to the brake drums or into the brake mechanism.

HYDRAULIC EQUIPMENT

Dowty Hydraulic Systems

THE actuation of retracting undercarriages, tail wheels, flaps, gun turrets, firing gear, bomb doors, control trimming tabs, engine cowl gills, etc., by means of hydraulic jacks, has become increasingly popular during the past few years, and this method of operation has been adopted by practically all aircraft constructors.

Probably the chief reason for this popularity is the fact that one central power unit, namely the pump (which may be engine or hand operated, or may be a self-contained electrically powered unit) can control all the components mentioned without the employment of torsion shafts, push rods or other mechanical power transmission means.

Again, the hydraulic control system offers an extremely simple means of gearing up or gearing down between the power unit and the operated device without resort

to worm shafts, gear wheels, or lever combinations, for it is only necessary to vary the piston areas of the different operating units to obtain the desired gear effect.

There are three main units common to all aircraft hydraulic installations ;—

1. A pump supplying oil under pressure.
2. A valve controlling the direction of flow through the pipe lines, and
3. Jacks operating the various components.

The simplest comprises a hand operated pump, a two-way control valve and a pair of jacks. The pump delivers oil under pressure to the jacks via the control valve which is so constructed that it allows the operator to change the direction of flow in the jack pipe lines, thus permitting extension or contraction of the jacks at will.

Oil filters are provided and a pressure relief valve is incorporated to prevent the flaps being lowered at excessive flying speed. This valve also permits the flaps to blow up if the speed of the aircraft is unduly accelerated.

When the engine is running, the engine-driven pump delivers oil continuously to an automatic cut-out valve, which normally allows the oil to flow direct to the reservoir via the filter. Under these conditions the pump is idling at no pressure. The pilot is provided with a single lever control for operating the undercarriage and flaps.

To avoid bringing pipe lines into the cockpit, this control lever is connected to the distributor valve box by remote controls such as push rods. Operation is as follows: to lower flaps, the control lever is moved out of neutral to the gate position labelled " Flaps down " and this actuates the distributor valve ; the automatic valve instantly goes into action and the pump supplies oil under pressure to the flap jack. When the jack piston reaches the end of its stroke, the automatic valve cuts off the supply and the pump then circulates oil under no pressure to the reservoir.

To raise the flaps the lever is moved to the opposite end of the gate labelled " Flaps up," and the cut-out valve again diverts the pump delivery to the jack circuit. It should be noted that in this system the flap jacks may be stopped at any point in their travel by returning the control lever to the neutral position, thus enabling the pilot to set the flaps at any desired angle. The hand pump is provided as a stand-by in case of failure of the engine-driven pump.

To prevent excessive pressure in any pipe line due to temperature variation, the distributor unit is provided with automatic relief valves to compensate for variations in volume.

Dowty " Live Line " System

The latest development in hydraulic installations powered by engine-driven pump is the " Live Line " system, using the Dowty Live Line pump, which is automatic in action and eliminates the need for cut-outs and accumulators. It reduces the number of hydraulic items to a minimum and thereby simplifies installation and operation and reduces vulnerability. Delivery from this pump ceases at a predetermined pressure and recommences immediately the pressure falls below this predetermined figure. Delivery is constant over a wide range of r.p.m. Delivery pressures up to 3,000 lbs. per sq. inch can be obtained and cooling is effected by constant oil circulation through the pump casing.

An advantage of this system is that the speed of jack operation can be adjusted to suit the particular requirement of the service they perform. This is accomplished by a restriction fixed or adjustable in one of the common jack lines. The effect is to produce a high pressure at the pump, causing it to react to an intermediate position, with correspondingly reduced delivery. The jacks therefore move more slowly.

Lockheed Hydraulic System

The hydraulic equipment on an aircraft such as the Phillips and Powis Master is used to operate the undercarriage and flaps, and to charge the brake accumulator. An engine-driven pump and a hand pump, fed from a common header tank, are employed to supply fluid under pressure, independently, to a selector valve which diverts the fluid to raise or lower the undercarriage and flaps. If the engine pump becomes inoperative, the hand pump will operate all services unless the emergency selector valve has been used.

Operation of the undercarriage is carried out by double-acting rams, termed " jacks," each wheel being raised and lowered by one jack, the ramrod of which is extended when in the latter position. The method of locking the undercarriage when in the landing position is by means of a sleeve being forced over a knuckle joint in the retracting member. In the retracted position the undercarriage is locked mechanically by a spring-loaded catch, and released by the first movement of the undercarriage jack forcing the locking sleeve against an extension on the catch.

The undercarriage can also be lowered by an emergency pipe line which is brought into operation by an emergency selector valve, in conjunction with clack valves on the undercarriage jacks. When in use the emergency selector valve cuts out the main selector valve, thereby bringing the hand pump into direct communication with the emergency line; at the same time the clack valves on the undercarriage jacks open up the emergency line and seal the main line.

If, however, the emergency selector valve has been put in the emergency position the flaps cannot be operated. It is therefore preferable to lower the flaps by the hand pump and main selector valve before using the emergency selector valve to operate the undercarriage.

The flap circuit has two jacks, the ramrods of which are extended when the flaps are lowered; and a flow control valve, which acts as a double hydraulic lock and releases the fluid automatically when pressure is applied; it also retains the flaps in any desired position after the main selector valve lever has been returned to the neutral position, unless the pressure on the flaps exceeds the setting of the flow control valve, in which case the flaps will rise until the pressures balance.

The accumulator, which is a reservoir for fluid for brake application, has three components in its circuit: a restrictor valve, which is set to relieve when the accumulator has been charged to the specific pressure; a non-return valve, which is contained in a four-way piece, and a trap valve, the former being to prevent fluid from returning to the engine-driven fluid pump when the hand pump is in use, and the latter to retain fluid pressure in the accumulator.

Operation of Lockheed Undercarriage and Flaps by Engine-driven Pump

(i) *To raise the undercarriage* :—Pull the undercarriage lever on the selector valve fully up and release. The lever will return, automatically, to neutral when the operation is complete.

(ii) *To lower the undercarriage* :—Push the undercarriage lever on the selector valve fully down and release. The lever will return automatically to neutral when the operation is complete.

(iii) *To lower the flaps* :—Push the flap lever on the selector valve fully down and release. The lever will return automatically to neutral when the operation is complete.

(iv) *To raise the flaps* :—Pull the flap lever on the selector valve fully up and release. The lever will return automatically to neutral when the operation is complete.

(v) *Intermediate position of the flaps* :—Should an intermediate position be required, the selector valve lever must be returned to the neutral position manually when the desired position is reached.

Care should be taken to ensure that the selector valve levers for flaps and undercarriage have returned to neutral. If automatic return has not taken place, the levers must be returned manually.

The selector valve levers may be operated separately or both together. In the latter case that service which requires the least hydraulic pressure will work first. Either lever can be returned to the neutral position, manually, at any time during the cycle of operations.

Operation by Hand Pump

The selector valve levers are operated as previously mentioned, and hydraulic pressure is built up by reciprocating movement of the hand pump handle. This method of operating the undercarriage and flaps should be employed if the undercarriage or flaps fail to function by means of the engine pump.

Emergency Lowering of Lockheed Undercarriage

To lower the undercarriage in emergency, cut out the main selector valve by releasing the safety catch and pushing the emergency valve knob fully down, and operate the hand pump. By this means the undercarriage only can be lowered and it should be employed when, for any reason, both the other means of operation have proved to be inoperative. The reserve head of fluid thus used is sufficient to lower the undercarriage once.

The hand pump should be operated until considerable resistance is felt. If the wing indicators show " Undercarriage down " the undercarriage will be locked down hydraulically and will be safe for landing even if the cockpit indicator does not show both green lights, which might be due to an electrical failure. In order to return the hydraulic circuit to normal, place the emergency selector valve knob in the normal position, select " down " on the main selector valve lever and, if using the hand pump, operate the handle till considerable resistance is felt, or, if using the engine-driven

pump, until the selector lever throws out automatically. The object of this is to move over the clack valves in the undercarriage jacks to their normal position and allow a free flow of return fluid through the normal circuit. The normal circuit should then be retested on the main selector valve in the normal manner.

Charging the Accumulator

The accumulator is charged automatically while the engine-driven fluid pump is running, as long as the main selector valve levers are in the neutral position. Charging by the hand pump can also be carried out as long as the main selector valve levers are in neutral.

Operating Pressures

The pressures required to operate the services, when the aircraft is not in flight, vary with the movement and should not exceed 750–850 lbs. per sq. inch. If the pressure under normal static loading exceeds the latter figure an examination should be carried out to determine the cause. If the normal loading is exceeded under test conditions, such as raising the undercarriage with twice the weight of wheel attached, then the pressure will rise to 1,050 lbs. per sq. inch. In this instance it may be necessary to hold the selector valve lever in the selected position during each movement.

Messier Hydraulic System

Certain features in the design of the Messier undercarriage, as used in the Halifax four-engined bomber, make it distinctive. The undercarriage itself is often made from a casting in magnesium alloy, a method of manufacture which is considered preferable to structures fabricated from steel tubes. These magnesium alloy bridges have been in use for a number of years and have proved to be strong, light and simple to manufacture.

Another feature of the Messier undercarriage is the patented system of "accumulation of energy." With this system the energy produced by a hydraulic pump is used to raise the undercarriage and at the same time store energy in an accumulator. Thus, on movement of the controlling distributor, the pilot can lower the undercarriage by means of the accumulator without having to operate the hydraulic pump once more.

This system ensures that the undercarriage is lowered in a few seconds, even if the engine of the aeroplane has failed. It is, therefore, a very valuable attribute to the hydraulic system in general.

The engine-driven hydraulic pump used with the Messier system is interesting in that it is provided with a mechanical clutch. As the pump is only operating in the system for a few seconds during take-off and not when landing, the clutch is considered an essential feature, so that the pump does not idle for long and unnecessary periods.

A newer development is the method of operating the clutch on the pumps automatically so that the pump is clutched in as soon as the pressure is required and declutched when the pressure rises to a predetermined amount. This relieves the pilot of all responsibility regarding the pump.

The hydraulic system operates at a pressure of 1,500–2,000 lbs. per sq. inch, which enables small sizes of pipe and components to be used.

The Messier shock absorber strut has been developed over a period of many years in conjunction with a specially designed drop test machine which enables the shock-absorbing characteristics of these struts to be investigated scientifically. Struts are in all cases provided with external adjustments and do not have to be dismantled to alter the damping orifices. The results obtained on this machine by successive adjustment of the orifices until the optimum positions are arrived at, enable high performance to be obtained. In some cases efficiencies as high as 93% have been achieved. The shock absorber struts are not only designed to absorb the energy of landing but are provided with extra openings, so that the restriction, or damping, during the middle of the travel of the strut around the static position is reduced. This gives excellent taxi-ing characteristics.

Although fully hydraulic brakes are used in some cases, it has been found preferable to use a combination of pneumatic and hydraulic control incorporating a relay. The pneumatic control is operated by the pilot and pressure is applied to the hydraulic part of the system on the wheels themselves by means of the relay.

A patented feature of the method of operating aeroplane flaps is known as the "Limitation of Effort." With this system flaps are put down by means of an accumulator so arranged that if a gust strikes the flap, the flap momentarily disappears to a small or large extent, depending on the strength of the gust. Once the extra load has disappeared, the flap once again resumes its correct position.

HOSE, UNIONS, AND FILTERS

Flexatex Hose

THE Flexatex range of hose includes types suitable for the conveyance of practically every kind of fluid. Each type is constructed from materials selected to suit the operating conditions.

Wilkinson research has produced in the Flexatex range a rationalisation of the whole method of flexible hose construction, supply and assembly. The unique design brings better relative performance than any other type. The special form of construction enables an untrained operator to assemble it *on site*. Standardisation has ensured use in conjunction with A.G.S. parts obtainable from any suppliers of ordinary straight or taper shank fittings.

Range of Flexatex Hose

At present there are six classes of Flexatex, and under each class there may be one or more types according to industrial requirements. There is, therefore, a type available to meet practically all known purposes.

Class	*For conveying*	*Class*	*For conveying*
C	Petrol	F	Chemicals
D	Air	G	Water
E	Oil	H	Gases

It is desirable that enquiries should always state the following :—

(1) General conditions of applications of hose.
(2) Fluid or gas to be conveyed.
(3) Maximum and minimum temperature of fluid or gas.
(4) Maximum and minimum temperature of exterior of hose.
(5) Working pressure.
(6) Maximum and minimum pressure.
(7) Minimum bend radius required.

Installation

The hose is supplied in unit lengths of 14 feet 6 inches long, and is designed to ncorporate straight or taper shank end fittings. It may be fitted to stub ends of rigid ipipes, and some types may be fitted to rigid pipes with beaded ends. For aircraft use standard end fittings have been designed, namely, Nipple A.G.S. No. 1151 and Nut A.G.S. No. 770 ; the sizes of hose supplied are ¼ inch to 1½ inches.

Electrical bonding between end fittings is unnecessary. Where the hose is in contact with vibrating surfaces it should be protected from abrasion by canvas or leather binding. It is unnecessary to pressure test hose before installation. Clips may be removed to facilitate installation, but must be replaced and secured before tightening union nut.

Construction

Flexatex hose consists of the following layers, from the inside :—

(1) *Resistant Lining* : This is an extruded flexible tube of material selected to resist the high aromatic fuels or other liquids to be carried.
(2) *Treated Felt* : This layer is a specially treated felt, which is bonded to the inner lining.
(3) *Non-metallic Wire* : This wire provides the flexing qualities of the finished hose. It is light and tends to recover shape after pressure. Its use removes any necessity for electrical bonding between the end connections in the hose.
(4) *Outer Covering* : This may vary according to requirements, being either a layer of synthetic rubber or suitable plastic, or a spiral wrapping of fabric treated with such material.

This type of construction has the following advantages :—

(1) The weight per foot run in many cases is less than existing flexible hose.
(2) The smooth bore allows for a greater flow of fluid than any other flexible hose of equal bore.
(3) The smooth bore also allows for the fitting of very simple end connections.
(4) The hose can be cut to length with an ordinary knife lubricated with water.
(5) Due to absence of metallic materials, electrical bonding between end connections is unnecessary.
(6) Cutting, fitting with end connections, and installation can be carried out by the assembly hand himself in a matter of seconds.

Lockheed Hoses

Lockheed Hoses are made from the same rubber mixings as Lockheed glands and have the same essential characteristics, and provided the correct Lockheed fluid is used they give almost indefinite service. The ultimate burst pressure is in the region of 6,000–8,000 lbs./inch², although this figure can be improved if required. The special method of attachment to the metal fittings at their ends has very considerable resistance to fatigue, but it is essential that the hoses should be used in such a way as to ensure that movement does not impose torsional stress between the hose and its end fittings. Also, the minimum radius of bend should be not less than six times the outside diameter of the hose.

Lockheed Pipeline fittings are designed to make use of Lockheed flared connections, which are an extremely simple and light form of attachment and in general use on many classes of work. The joint, although simple, requires certain precautions in construction. The flare should be made by means of a Lockheed flaring tool, and should be large enough so as to pass into the tube nut or adaptor with a diametri al clearance of not more than .015 inch. Also the connection does not require excessive tightening, and approximately one-sixth of a turn after the flare is first napped is quite sufficient to form a perfect seal. A large range of standard fittings is available for the installation of the pipe lines in the air frame.

Palmer " Silvoflex " High-pressure Hose Units

Palmer Silvoflex high-pressure hose, for hydraulic control, petrol and hot oil systems, has solved a number of pressing problems for aircraft constructors.

Vibration, for example, has always been destructive to pipe connections. Copper tubing has been particularly subject to premature failure due to crystallisation at the end fittings, leading to early fracture. Various types of flexible hoses have been tried, but troubles have arisen owing to poor oil-resisting qualities and to fluctuations of expansion under pressure, with consequent loss of efficiency of the hydraulic system.

Palmer Silvoflex was designed to overcome these difficulties. The construction comprises :—

(*a*) An oil-resisting tube is of synthetic rubber, specially compounded to maintain full efficiency at temperatures ranging from minus 35° C. to 150° C. The technique of processing this compound was only achieved by elaborate research and is the determining factor of efficiency. It cannot be attained by the mere mixing of ingredients obtained by chemical analysis.

(*b*) The braided metal reinforcement in Palmer Silvoflex hoses may consist of one or more layers of high-tensile steel wire. The best type of steel for this work, and the construction of the braiding machine, were determined by protracted experiments and are special to the product.

(*c*) Both the steel wire and the cotton braiding are thoroughly impregnated and insulated by synthetic rubber compound, and the fabric is protected by

(*d*) A cover of synthetic rubber, again specially compounded to provide adequate resistance to sunlight, temperature and varying atmospheric conditions, as well as to the effects of oil.

All Silvoflex units are electrically bonded and individually tested at the specified hydraulic pressures as well as for static and free flow.

Supplied only as Complete Units

It has been proved beyond question that Palmer Silvoflex hose can function efficiently and withstand the service conditions only if couplings of the right type are expertly fitted. Palmer, therefore, retain direct control of this vitally important work, which calls for the greatest skill and supervised craftsmanship to avert the risk of blowing-off or leakage, and *Silvoflex is* Silvoflex *only as units complete with end fittings.*

Silvoflex couplings are of a patented type and are available with standard unions, the nut threads and cone nipples of which are interchangeable with A.G.S. Standards. Male ends, right-angle fittings and banjo types can be supplied, but wherever possible the standard types should be adopted in order to avoid delay in delivery.

A useful range of standard hose units, from ⅛ inch to 2 inches i.d., has been established, and these can be of any length up to 50 feet.

Petro-Flex

Petro-Flex is a strong light-weight flexible tube which is unaffected by the action of petrol, benzole or other kinds of motor spirit. It may also be safely used for the conveyance of both mineral and vegetable oils in cases where temperature does not

exceed 70° C. Approval for the use of Petro-Flex Tubing on aircraft was granted— by the Air Ministry in 1923, and, since that date, it has been constantly used by the Air Ministry and the leading aircraft constructors.

The tubing is constructed as follows :—

(1) Many layers of indestructible spirit proof lining.
(2) Treated canvas outer protective covering.
(3) Internal and external helically wound armouring.

The tubing is made to Air Ministry Specification D.T.D. 1009, which covers three classes of manufacture :—

Class I. Used for petrol pipes on aircraft.
Class II. A heavy type of tubing used for ground equipment refuelling or re-oiling purposes.
Class III. A light type of refuelling hose carried on aircraft.

Installation

To obtain the best results under working conditions, it is essential that Petroflex be mounted in such a way that, when it is not under load, it shall be free of all tensional and torsional strains. All bends should be as wide as possible, and the minimum bending radii should not be exceeded. In cases where the tubing is longer than 2 feet in length, it is advisable to clip the pipe to some rigid part of the machine, to prevent chafing and to relieve it from strain due to swaying.

Petro-Flex Extra-high-pressure Tubing

Although Petro-Flex X.H.P. tubing has been developed to deal with hydraulic operation of various controls on aircraft, it can also be applied to other forms of mechanism. In effect, this tubing is of the same quality as the Aircraft Petro-Flex tubing, but it has the addition of a strengthening external wire-braided cover.

Unions for X.H.P. tubing have been designed for working pressures of 700 lbs., and maximum pressures for short periods, 900 lbs. per sq. inch at a test temperature of 60° Centrigrade. These unions are entirely new in design, and application for patents covering their construction has been made. The following sizes are now available: $\frac{3}{16}$ inch, $\frac{1}{4}$ inch, $\frac{3}{8}$ inch, $\frac{1}{2}$ inch, $\frac{5}{8}$ inch, $\frac{3}{4}$ inch, $\frac{7}{8}$ inch and 1 inch.

Normally pipes are fitted with straight unions of British Standards pipe thread of the equivalent size, with the exception of $\frac{3}{16}$ inch bore tubing, which is fitted with unions of $\frac{1}{4}$ B.S.P. Elbow unions or unions of other special types can be supplied if required.

Superflexit Fuel and Oil Pipe Lines

There are two main types of flexible tubing, one metallic and the other non-metallic. The first consists of thin metal strip specially formed to give continuous interlocking spiral sections, the joint between the sections being sealed by suitable jointing, usually in the form of a fabric or rubber thread. Over this flexible metallic conduit, various types of covering are applied to give additional strength and resistance to external conditions.

The non-metallic tubes are made up of a spiral of wire around which is wrapped a suitable material having high resistance to the action of fuels and oils. The material is frequently in sheet or strip form, the layers of which are coated with a suitable adhesive whilst being wrapped round the wire spiral. The conduit thus formed becomes the liquid carrier. Over this conduit various types of covering are applied to provide the necessary strength and to meet whatever external conditions may prevail.

The wire armoured type can usually be obtained in two colours, red and black, so that if desired, differentiation can be made between fuel and oil pipes by colour.

Weight

Flexible metallic tubes are heavier than non-metallic and thus, providing the choice is open, the latter should be used where weight is a serious consideration.

Movement

All types are suitable where the movement is confined to one plane. In cases where the movement is in more than one plane, it will generally result in a torsional strain being applied to the tube. For such applications flexible metallic tube should not be used, as a twisting movement tends to open the joints.

It is therefore necessary to select a non-metallic tube. Further, tubes having an an external covering of wire braiding are not suitable, as the braid resists any twisting action and if this was continually applied the braid would ultimately fracture. The most suitable tube is therefore one of non-metallic construction having a wire-armoured covering. Most makes of this type of tube can be safely twisted through 180° without harm.

Bonding

To eliminate the danger of sparks occurring between two members, which, due to electrostatic fields or static charges, may be at a different potential, all metal parts of an aeroplane should be bonded together. It will, therefore, be appreciated that a flexible tube joining two metal parts must be electrically continuous from union to union. In some makes of tube, special provision has to be made for this, and it is important that any flexible tube used should fulfil this requirement. In addition, the bonding reduces interference with wireless signals on aeroplanes so equipped.

It will be appreciated that good electrical contact must also exist between the union of the tube and the part to which it is attached. In most cases this is ensured by direct metal to metal contact. But with duralumin fittings which have been anodically treated, the anodic film acts as an insulator and some provision must be made to ensure continuity. This is usually achieved by the wire used for locking the union nut. The hole through which this wire passes is always drilled after anodic treatment, and consequently the wire passing through the hole makes good electrical contact with the duralumin.

Screening

Flexible tubes having an outer armouring in the form of a spiral of wire produce an electrical capacity and inductive effect which interferes with wireless signals. To eliminate this interference, the convolutions of wire must be short-circuited. This is done when the tube is made, by providing a continuous length of copper flex underneath the wire armouring, which is thereby short-circuited.

Where the outer covering is a metallic braid, this acts as a screen and the flex is not needed. The metallic braid must, however, be non-magnetic and therefore usually consists of either copper or bronze wire.

Unions

All unions have to conform to designs approved by the Air Ministry, and the standard design for use on aeroplanes is a spherical seated female union. Nuts are drilled across the corners, to provide for a locking wire. All duralumin unions must be anodically treated before use and the locking wire hole drilled after this treatment.

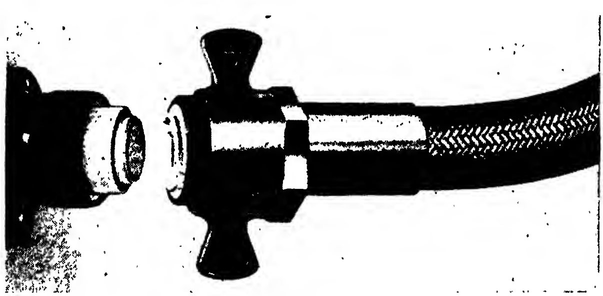


Fig. 305.—External appearance of Avery self-sealing coupling.

As mentioned previously, it is essential that all tubes should provide electrical continuity, and it is therefore important to see that the anodic film on duralumin unions is removed where the body of the union and the nut are in contact. This can be done by holding the union in one hand and revolving the nut with the other, and at the same time pressing the nut against the shoulder of the body. Similarly, on the portion of the union which enters the tube, the anodic film must be removed by scraping where it comes in contact with the metal portion of the tube.

In addition to straight unions, elbows are also used. When it is necessary to use an elbow, consideration must be given to the hydraulic resistance caused by such an acute bend.

The choice of the material from which the union is to be made is important. First, it must be to a specification approved by the Air Ministry. Weight may then be the next important consideration, and where this must be reduced to the minimum, duralumin should be used. Otherwise, brass has the merit of being cheaper. Where the unions are composed of more than one part, care must be exercised owing to voltaic action occurring with dissimilar metals. This is particularly the case with brass and duralumin, a combination to be avoided. Further, it is better to avoid parts using duralumin for two fittings which screw together, as seizure is likely to occur. Where a female union is to screw on to a duralumin part, it is usual to make the body of the union in duralumin and the nut in stainless steel. If the whole of the union, including the nut, is of duralumin, then the male part to which it is to be attached should be of stainless steel.

The most common material specifications as approved by the Air Ministry for unions are :—

B–6	Naval brass bar.
B–13	Brass bar.
L–1	Duralumin bar.
S–80	High chromium steel.

The Avery Self-sealing Coupling

This is a patented coupling developed by Avery Equipment, Ltd., of Leamington Spa. Although primarily intended to facilitate the rapid connection and disconnection of pipe lines in aircraft hydraulic systems, it has numerous other adaptations in piping

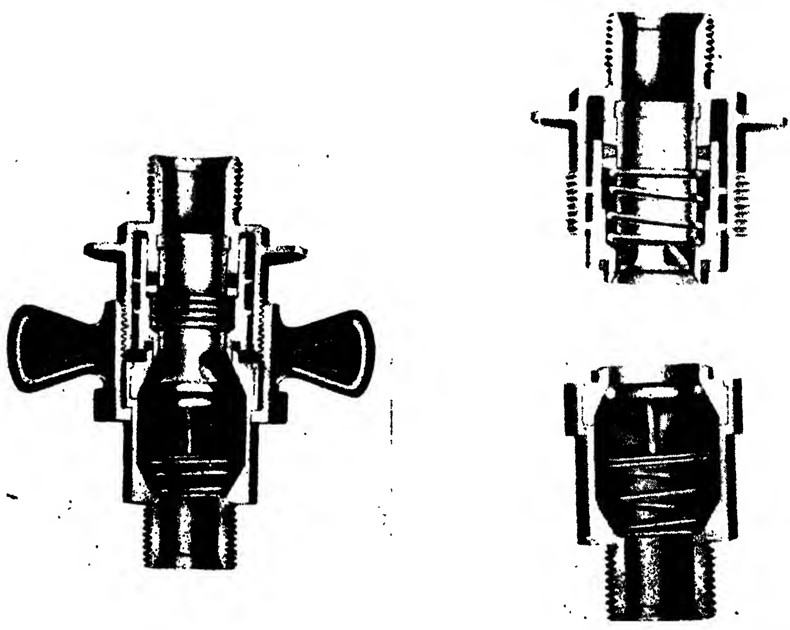


Fig. 306.—Avery self-sealing coupling, connected, and disconneetcd.

systems of all kinds, carrying almost any type of fluid in common use, including fuels, coolants, lubricants, water, de-icer, fire extinguisher, hydraulic fluids, etc. The main feature of the coupling is that it enables any pipe line to be connected or

disconnected quickly and without the loss of contents or the admission of air into the system. In addition, the operation can be carried out whilst either or both halves of the coupling are under full working pressure. The lengthy operations of draining the fluid from the system prior to disconnecting the units and re-priming them after reconnection are also eliminated.

It will be seen that the Avery Coupling is an invaluable component to facilitate assembly in unit construction of aircraft and to speed up the operation of changing power units or engines in almost any type of aircraft without disturbing the main hydraulic system. By their use, components and units can be changed in a fraction of the time which would otherwise be required when the system would require draining and refilling, etc.

The method of making and breaking the coupling is carried out in the customary manner, i.e., screwing up or unscrewing a union nut. The sealing is effected by means of a fixed valve with a spring-loaded movable seating in one half of the coupling and a fixed seating and movable spring-loaded valve in the other. The action of tightening the union nut causes the valves in each half to open so leaving a free passage for the fluid. When fully connected as shown in the illustration the apertures thus obtained are equal to the cross-section of the pipe line and the resistance to flow through the coupling is negligible at normal velocities. The possible working temperatures may be from $-60°$ F. to $400°$ F.

There are eleven sizes of Avery Couplings available ranging from $\frac{1}{8}$ inch to 2 inches in diameter. In the standard pressure range the normal working pressure may be up to 1,200 lbs. per sq. inch, with peak pressures up to 1,750 lbs. per sq. inch. A heavy duty type of coupling has recently been introduced made almost entirely of steel alloy which permits of working pressures up to as high as 5,000 lbs. per sq. inch in circumstances where the additional weight is of no consequence. The Avery Coupling and hose are now standard equipment on many leading aircraft.

Avimo High-pressure Pipe Couplings

The Avimo Coupling is designed in such a manner that the joint can be easily broken, will withstand very considerable pressure when assembled and provides a slight degree of resiliency. Alignment of the pipes should be as true as possible and it is not recommended that the coupling should accommodate mis-alignment exceeding $\frac{1}{16}$ inch for all sizes up to 3 inches. Angular mis-alignment requires the use of two complete couplings as a single coupling is not satisfactory.

The principal use of the coupling is for the cooling systems of aero engines, and it is designed to be impervious to the effects of water, glycol and oil at a very wide range of temperatures and pressure.

The design of the coupling is very simple. Sleeves are secured permanently on the ends of the pipes to be coupled and provide the special external corrugations on which the remainder of the coupling is assembled. The special shape of these corrugations, or grooves, and the shape of the synthetic rubber sleeve, before compression, are such that when the outside clip is undone and pressure taken off the rubber this tends to ease itself from the corrugations and so the joint can be easily separated.

Sleeves are supplied in various materials to suit the metal of the pipes. Steel sleeves are brazed to steel pipes, brass sleeves are brazed or sweated to brass and copper pipes. Aluminium sleeves are provided with a special inside chamfer to facilitate the welding to aluminium pipes. It is particularly important with aluminium that the sleeves are a good fit on the pipe because any movement of the pipe inside the sleeve would be liable to cause a failure of the welding. A smooth radius is provided inside the sleeves to facilitate the smooth flow of the liquid.

The *synthetic rubber sleeve* is of a special composition designed to withstand the corrosive effects of the liquids in the pipes. It is sufficiently flexible generally to be pulled through between the pipes to be coupled or when this is not convenient it can be slipped right over one sleeve to enable the pipe or unit to be removed. The rubber does not stick on the sleeves and with reasonable care it is possible for it to be used repeatedly.

The *packings* are a very important part of the coupling and are made as two semi-circular pieces to fit snugly over the rubber sleeve. Lateral grooves are provided which form spaces into which the rubber may flow when the outer clip is tightened and the rubber compressed, this ensures an even distribution of pressure around the coupling. These grooves also act as stiffeners to prevent failure of the packings by distortion in the event of unusual pressure. Small protruberances on each groove provide a location for the outer clip and prevent it slipping to one side. The packings

are made of steel and protected from corrosion by zinc plating, for use on flying boats, or where extra corrosion may be expected, cadmium plating can be supplied.

The Jubilee Clip has been selected as the standard outside clip, but some other makes are suitable. It is necessary to have a clip which can be fitted around a pipe as those in a complete ring are not suitable.

When assembling the coupling care must be taken to see that the space between the packings is maintained equal; when tightening the clip there is a tendency for one packing to rotate slightly. The bridge portion of the Jubilee clip should be about the middle of one of the packings and should be on two of the grooves. Also the clip must rest between the locating protruberances on the grooves on the packings. The above points can easily be checked by feel and therefore there is no difficulty about making a joint in the dark. The only tool required is an ordinary screwdriver.

When tightening the clip it is only necessary to apply enough force to compress the rubber sufficiently to stop leaks. It is obvious that the rubber serves a useful purpose in damping out vibration and that excessive tightness impairs this quality and puts an unnecessary strain on the packings and clip.

It should be noted that the joint itself is not electrically bonded, since no provision is made for this purpose. Bonding across the joint must, therefore, be made with the usual strip and clips in the ordinary manner.

The standard range of sizes covers pipes from ½ inch to 3½ inches outside diameter. Sleeves with screwed bosses, double sleeves with an integral flange for bulkheads and sleeves formed as part of components are some of the special adaptations made.

Dowty Filters

Filters prevent foreign matter circulating continuously through the hydraulic system. Dowty Equipment, Limited, produce a filter designed to prevent loss of oil when the unit is dismantled for cleaning.

A sleeve inside the filter has openings corresponding with the pipe connections. When the base is removed this sleeve is automatically rotated to close off the ports.

As the pipe lines cannot admit air during the cleaning process, bleeding is unnecessary. The filter is refilled with oil after assembly by removing a plug in the dome of the body.

The filter element consists of a corrugated felt tube reinforced internally by a woven wire mesh. Oil passes from the outside of the felt tube to the inside and then through the centre tube to the outlet connection.

A smaller type of filter commonly used on hand-pump installations consists of a light alloy body with a removable base and a filter element of corrugated felt reinforced by a woven wire mesh.

In both the units described a coil spring in the centre of the tube prevents collapse of the filter element under pressure.

Tecalemit Hydraulic Filters for Aircraft

The success achieved by the Tecalemit "full-flow" oil filter is basically due to the filtration medium which removes all foreign solid matter from the oil, likely to be injurious to rubbing surfaces and bearings, down to a size as small as 25 microns.

It is known that particles of foreign matter hard enough to cause damage are usually dense in character and might be assumed to settle out of suspension, but the fact remains that particles do nevertheless reach the bearings and rubbing surfaces, unless a "full-flow" filter is interposed. This is of the utmost importance in hydraulic circuits used in modern aircraft.

The Tecalemit Oil Filter type O.F.2790, designed for hydraulic circuits, comprises a built-up sheet metal container, a cleanable and renewable filtering element having a steel mesh frame for supporting a cover of specially developed felt, and an aluminium top casting in which is embodied a barrel type valve which must be opened before the element and container can be removed. The opening of this valve closes the hydraulic circuit during the dismantling period, thereby eliminating the necessity of draining the system.

The filter operates at pressures up to 100 lbs. per sq. inch, the pressure drop due to the oil passing through the element being less than 1 lb. per sq. inch.

Other types of filters are available for hydraulic circuits designed to operate at pressures up to 3,000 lbs. per sq. inch. Filters on this principle have for a number of years been standardised on some leading aircraft engines.

Whilst the principle of design has remained virtually unaltered for eleven years, research has rendered it possible to develop these filters in detail for a large number of varying applications to military aircraft.

ELECTRIC WIRING

Callender's Electric Cables for Aircraft

ELECTRIC cables for aircraft are produced in two main categories, low tension and high tension. The use of the latter is confined to ignition systems (for connections between magnetos, distributors and sparking plugs), but the former is used for very many purposes, including lighting, heating, telephony, radio, remote control, warning signals, generator and battery connections and for power circuits (for the operation of flaps, retractable under-carriages, etc.).

Each type of cable is built up from conductors of standard sizes, insulated in accordance with the appropriate specification, and then finished in the most suitable manner for withstanding the conditions under which it is to operate. Many special finishes are necessary, each being designed for special duties. Space does not permit each of these being described, but the most common finishes are as follows :—

Cotton braiding for general interior circuits such as lighting, intercommunication telephones, etc.

Cellulose varnish for cables that have to withstand petrol vapour and moisture.

Metal wire braiding for cables requiring mechanical protection against damage and also for multi-core cables that have to be " screened " to prevent radio interference.

There are also special finishes of heat-resisting material for ignition cables subject to high engine temperatures.

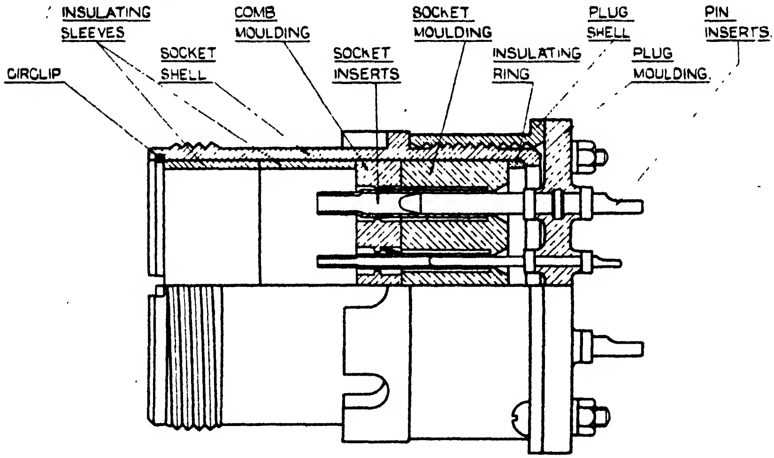


Fig. 307.—Sectional diagram of Breeze socket and plug.

Generally speaking, these cables may be made in single or multi-core types, and the first syllable of the type name of the cable (Uni-, Du-, Tri-, etc.) indicates the exact number of cores.

As a modern aircraft, particularly a large multi-engine type, requires very considerable lengths of different sizes and types of cable a definite means of identifying individual circuits is essential, and for this purpose colour is used so that in addition to the varying number of coils and special finish necessary the colour is important and indicates the exact purpose of the circuit. The colour scheme is, however, usually confined to the low-tension installation, and in multi-core cables which have tough rubber or metal braiding it is the insulated cores which are specially coloured for identification of circuits ; this colouring should not be confused with the external colouring above mentioned.

The Breeze Wiring System

The Breeze wiring system for aircraft consists of the application of the well-known Breeze plugs and sockets to the " Multiple connecting " of the conductors joining the various electrical accessories of each electrical service on the craft.

The method of applying this principle is entirely original in this respect, and has been devised by the engineering staff of the Plessey Company, Limited. The result is a system which can be mass produced at any dispersal point, together with a rational and orderly approach to the elimination of the increasing complexities of clectrics in aircraft.

It should be noted that the haphazard application of plugs and sockets of the Breeze type for such a purpose is not considered by the company to be in conformity with the Breeze wiring system as approved by them.

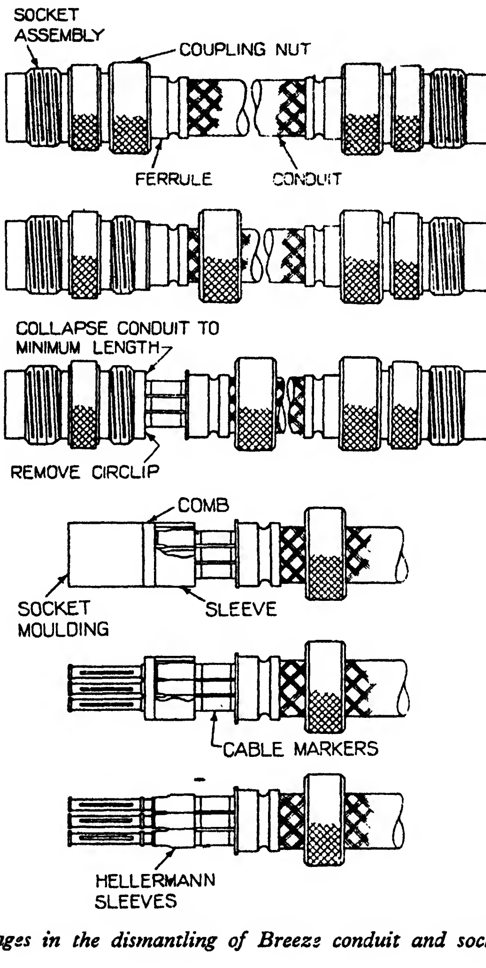


Fig. 308.—Stages in the dismantling of Breeze conduit and socket assemblies.

General Description

The Breeze conduit wiring system is one in which all the wiring is made up in units on the bench and assembled in the aircraft by means of multiple plugs and sockets. It consists of:—

(i) A number of flexible conduit or cable assemblies which may contain combinations of 4, 7, 19, 37, 64 and 200 amp. wires, each of which terminates on an appropriate metal socket pin assembled in a single bakelite moulding and enclosed in a metal housing.

(ii) A number of junction boxes or panels on which are mounted multiple plugs with suitable combinations to accommodate the socket assemblies.

The junction boxes also contain designated terminals for all circuits going through them.

(iii) A number of multi-pin bulkhead plugs which act as disconnection points at section breaks.

Advantages of the Breeze System

An approved method of tagging and rubber sleeving all connections, whether in a conduit or junction box, reduces to an absolute minimum the risk of disconnection of contacts due to excessive vibration.

The idea of installing the electrical wiring as completed units after the construction of the aircraft is practically completed, reduces the actual installing time spent on the aircraft to a minimum, with the resultant minimum interference to other workers on the machine.

Fault location is a simple matter owing to the fact that every wire is designated at both ends and a routing chart is provided which shows every plug and socket point (also numbered) in the circuit.

Fault rectification is simplified by the fact that the entire conduit or junction box affected can be rapidly removed and replaced. The damaged item can be repaired on a bench, or a like part can be drawn from the stock and fitted. Where severe damage is present this is an obvious advantage.

The system may be supplied unscreened or screened according to requirements.

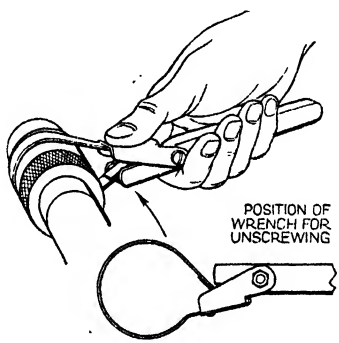


Fig. 309.—Strap type of wrench for manipulating Breeze assemblies.

The careful design and extreme compactness of Breeze Multiple Plugs and Sockets is illustrated by the fact that a Breeze multiple plug and socket occupying a space two inches square will accommodate nine 7 amp. plus sixteen 19 amp. designated connections. As a further example, it may contain twenty 7 amp., four 19 amp. and three 37 amp. designated connections.

The aircraft can be built in sections and each section can be " Breezed " separately, bulkhead plugs providing the connection link when they have been bolted together. This feature is particularly useful for carrying the engine services through the fireproof bulkhead, for aircraft with detachable wing sections, and for pressure cabin requirements.

General Design Procedure

The installation for engineering purposes is divided into three main systems :—

(*a*) General Services System.

(*b*) Bomb Fuzing and Release System.

(*c*) W/T and Intercommunication System.

Systems (*a*) and (*c*) will be required on nearly all types of aircraft. System (*b*) will be required on certain types of military aircraft only. Certain aircraft may also include additional systems, which are similarly treated for engineering purposes.

The aircraft requirements for all services are established and a theoretical wiring diagram (TWZ) is drawn up. This is a simple drawing showing the source of supply,

fusing and theory of each circuit, together with its appropriate standard circuit reference letter.

The appropriate location of each piece of equipment is ascertained and shown on a layout (KZ), a separate KZ being drawn-up for each system. These are a plan outline of the aircraft, showing section and bulkhead breaks. On the KZ the various circuits are routed and the positions for the necessary junction boxes are indicated, care being taken to keep the W/T equipment as far away from the other services as possible.

The conduit "runs," junction box locations and bulkhead breaks are confirmed with the aircraft designer and information as to space available for their reception is obtained.

A routing chart (RWZ) is now drawn up for each of the systems showing in straight-line form the route taken by and size of every wire in the installation via panels, junction boxes, conduits and bulkhead plugs.

Wiring diagram (WZ) of the junction boxes and fuse or control panels are drawn up on which the necessary terminals and plug points are shown. "Transfer" circuits may be wired from point to point on the plugs when circumstances warrant and permit. It is now possible to determine the plugs suitable for carrying the various leads between any two junction boxes.

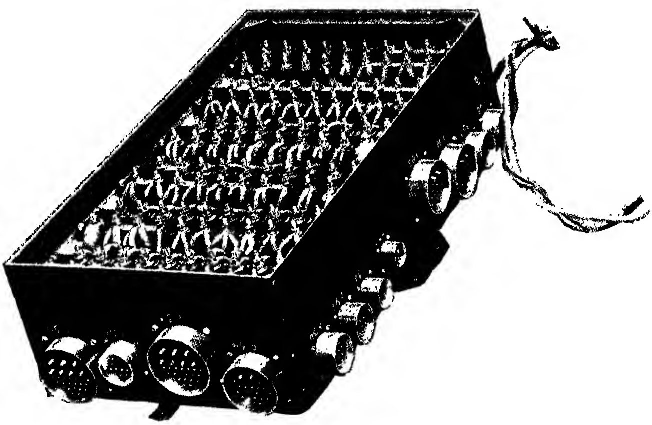


Fig. 310.—A main electrical panel completely assembled, ready for installation, by mass-production methods.

Assembly drawings (CZ) of the junction boxes are then made which give the actual size of the box, fixing centres and positions of plug outlets.

The aircraft designer is again consulted to confirm the physical suitability of the boxes in relation to the aircraft and the type and size of each cable or conduit for each junction box assembly.

The conduits, cables and junction boxes are finally established on the KZ drawings.

Finalised assembly drawings (CZ) of the conduits and cables are then completed, the junction box drawings also finalised and terminals designated with their appropriate circuit reference letter.

Installation

This is the entire responsibility of the constructor, who has, where required, the services on his premises of a Breeze resident engineer and/or service engineer. They are able to assist on any queries affecting the design or installation of the system in regard to alterations, etc., and act as consultants where necessary. Since the whole Breeze equipment is approved by the aircraft constructor and designer in regard to its accommodation in the machine, the former therefore provides all drawings necessary to show the method of fixing and cleating, position of junction boxes, and runs of all cables and conduits. It will be seen that installation of the equipment follows exactly the

requirements as laid down by the aircraft constructor. In general, the procedure adopted will be as indicated below :—

(*a*) The installation is usually done in sections, depending on the sectional breakdown of the machine.

(*b*) The junction boxes are first secured in their respective sections by means of screws or bolts. The associated conduit and cable assemblies are installed and clipped to the airframe structure.

(*c*) The conduit and cable sockets are screwed to their respectively referenced junction box plugs, the coupling nuts finally locking the attachment. It should be noted here that before attempting to screw a socket into a plug, the conduit coupling nut must first be slackened off. This is necessary in order that the socket shell is free to rotate independently of the conduit shell. A caution label is fitted to all junction box lids drawing attention to this requirement prior to the removal of sockets from plugs, during subsequent disconnections. When all airframe sections are finally assembled, the inter-section connecting conduits are correspondingly joined up and the machine is then fully wired.

(*d*) A complete end-to-end test is then carried out.

Siegrist's Latex Sleeves and Cable Markers for Binding Electric Wires

The finishing off of electric cables with rubber sleeves which stay on the cable under tension is a fairly old process. So far these rubber sleeves have been made of extruded crude rubber which, although quite flexible and strong, has one great disadvantage. Crude rubber is not flexible enough to bind, for example, a large cable and its core at the same time. A small sleeve of $\frac{1}{16}$ inch inside diameter could not be stretched sufficiently to go over a cable of $\frac{3}{8}$ inch or $\frac{1}{2}$ inch diameter, and if a larger tube was used, it did not cover the core and left an air gap where moisture entered, and it is just this which is the most important thing for sealing cables of aircraft.

Latex sleeves are extremely flexible, have a higher tensile strength and ageing properties, since latex is the natural juice of the rubber tree and retains its full strength of an unadulterated substance before it goes into production. Sleeves with a bore of 2 mm. can be stretched sufficiently to cover a cable of up to $\frac{3}{8}$ inch diameter and a sleeve with a bore of 3 mm. is sufficient for a cable up to $\frac{3}{4}$ inch and $\frac{7}{8}$ inch.

Uniform thickness varies from that of tissue paper thickness up to 3 mm., and even a sleeve with the thinnest wall has sufficient strength to grip the cable, and even to reduce its diameter by the enormous tension.

The sleeves can be made in bright colours, and as cable markers can be printed in black, red or any other colour. The latest introduction is now printing in white on black sleeves, which so far has not been possible. Printing in any colour is absolutely indelible and cannot be rubbed off with any solution, or even by scraping with a sharp instrument. Sleeves can be stretched to ceiling limits without splitting.

Multicore Solder

For years, firms engaged on the manufacture of electrical and radio apparatus, involving many soldering operations, have been seeking for a method of ensuring that the correct proportions of solder and flux are applied as rapidly as possible to components to be soldered.

Faulty Joint Problem

The bugbear of firms engaged on extensive soldering operations has been "dry joints." A "dry joint" is one which, to the eye, appears to be a sound joint, but which, in fact, is of high electrical resistance, due to the solder not having "wetted" on to the component. "Dry joints" are often difficult to detect during production and usually only become apparent if the wire or component that has been soldered is pulled by hand, or the piece of apparatus is subject to the usual vibrations in transit, when the joints come apart.

It will be obvious that "dry joints," apart from slowing down production, may involve the manufacturer in expensive service costs or, in the case of vital apparatus, may lead to more serious consequences.

"Dry joints" are usually due to one or more of three factors—insufficient heat during the soldering operation, insufficient supply of flux, or the use of a flux that is not active enough to remove the surface oxides before soldering, or to prevent them forming during the soldering operation.

The production of a solder wire containing a core of rosin flux was a contribution towards eliminating dry joints, but there are some inherent defects in the use of a solder

Fig 311.—*Expanding a Siegrist Latex sleeve before slipping over cable end.*

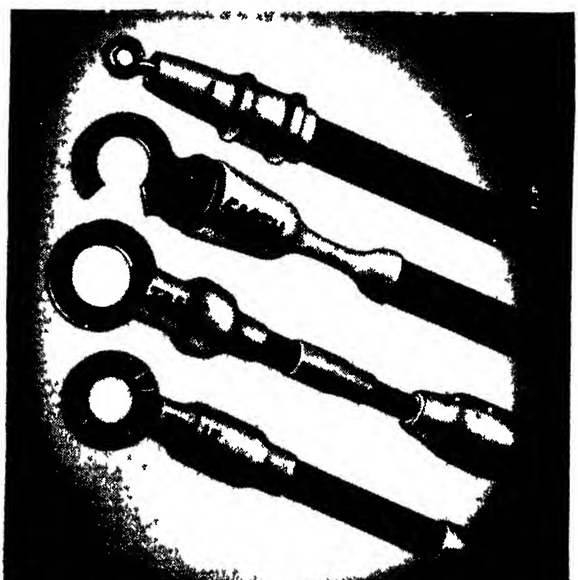


Fig. 312.—*Types of Siegrist cable markers.*

wire containing a single core of flux. It is practically impossible to produce a wire with a single core of flux without having some lengths of the wire without any flux at all. Cored solder is usually extruded in a diameter of ½ inch and then diminished to the required finished diameter by drawing; thus, if 24 inches of solder were extruded with no flux in the core, the detection of the faulty wire would be practically impossible, and when drawn out to 16 SWG the resultant length of wire would become approximately 800 inches, or enough solder to make nearly 2,000 connections.

Multiple Cores

There is only one way of being certain to overcome this difficulty in manufacture and it is the obvious one of making the wire with more than one core in it, each core being independently fed, and so arranged in number and size that should a stoppage occur in one, flux would continue to be present in the remainder.

Cored Solder Specification

British Standards Specification No. 441—1932 for "Cored solders, rosin filled," states that the ratio of flux to solder shall not be less than 3% or more than 5% by weight. Although these limits are generally accepted by users, it has been found in practice that, provided the flux core is perfectly uniform in size throughout the length of wire, a 2% ratio is quite satisfactory for ordinary use. In the manufacture of multicored solder three cores are used giving a 4½% flux ratio, therefore, if one fails over a section of the wire there is still a 3% ratio remaining. Apart from this merit, multicored solder has other advantages over single-cored solder. By employing a plurality of cores, it has been found that the distribution of the flux at the time of soldering is much more even, and better joints are obtained in this way.

In a wire of any given diameter a series of small cores in the place of one core ensures that the walls of solder surrounding the cores are thinner, and this effect makes the solder melt more readily when heat is applied, with a consequent speeding up of production. As a result, a multicored solder with a 55% tin alloy will behave in practice like a 60% alloy with only one core. The fact of being able to use 5% less tin and obtain the same results in practice means considerable saving in cost.

Non-corrosive Flux

Whilst rosin is usually specified as the flux for making connections on electrical apparatus, where subsequent corrosion must be avoided at all costs, it does not possess the function of removing oxides prior to soldering, as well as preventing their formation during the soldering operation.

Multicore Solders, Ltd., of London, were not satisfied just to incorporate the usual rosin flux, and thus Multicore solder has three cores of a special non-corrosive flux known as "Ersin."

Ersin flux is a pure high-grade rosin. Rosin as a flux suffices only as an agent to avoid oxidation during soldering, whereas Ersin will not only remove surface oxides, but also prevent their further formation during the soldering operation.

Ersin is approved by British Government departments for use in the construction of radio and electrical apparatus and may be used wherever rosin is specified.

By precision methods of manufacture, Ersin Multicore solder is produced in as fine a diameter as 22 SWG, that is, about ¾ mm., or as coarse as ⅛ inch. 16 SWG (0.064 inch) is the diameter of Ersin Multicore solder used by many of the leading manufacturers.

CONTROLS

Exactor System

THE principles of the Exactor system of hydraulic control, and the many unique advantages which this system offers in the solution of remote control problems of all kinds, are appreciated by an increasingly large proportion of the engineering industry and of the aircraft industry in particular.

For those who are not already familiar with the Exactor Control, it should be explained that the design has been evolved to meet the modern demand for a positive and accurate system, which will transmit movement over the long distances now frequently encountered without any backlash or lost motion whatsoever.

It is not intended to provide any power-advantage, or servo action, but to transmit such loads as may be applied to hand levers of normal lengths.

Each control is completely self-contained, incorporating its own fluid reservoir and requiring no engine-driven pumps or other accessories; all that is necessary is to mount the units, and run a single small-bore pipe between them.

Technical Description

Fig. 313 shows the standard general purpose Exactor Control, upon the design of which are based all the many developments and variations which have been introduced to suit different requirements.

It consists of two elements, known as the transmitter and receiver units respectively, connected by a single $\frac{3}{16}$ inch O.D. pipe line; the system is completely filled with a non-freezing fluid, which is used as a medium whereby movement of one unit is transmitted to the other.

The transmitter unit is fitted with a hand-manipulated lever, any movement of which will be reproduced by a lever carried on a shaft projecting from the casing of the receiver unit; this lever on the receiver unit is coupled by means of a suitable linkage to whatever mechanism it is required to operate.

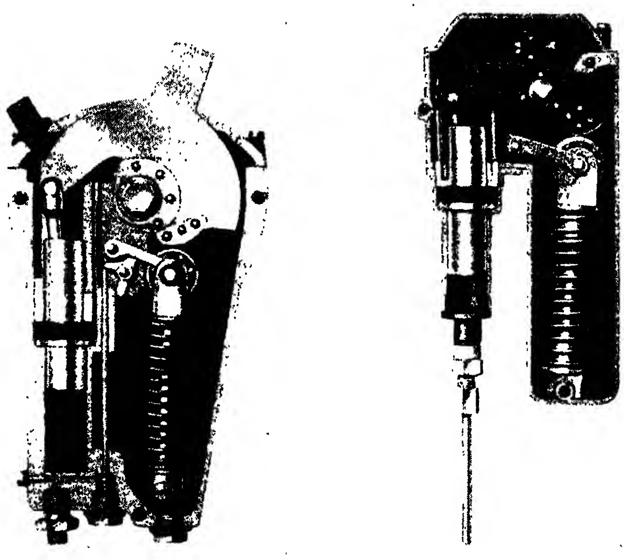


Fig. 313.—*Exactor transmitter, left; and receiver, right.*

It will be seen that the transmitter unit and the receiver unit are each provided with a similar trunk-type piston, carried on a rocker, and working up and down in a cylinder; the lower ends of these cylinders are connected by the pipe line.

Since the bore of the two cylinders is exactly the same a given movement of the transmitter lever will, by moving the transmitter piston up or down, import an identical movement to the receiver piston and hence to the lever keyed to the receiver shaft.

The fluid in the system is kept under pressure at all times by means of opposed compression springs acting on the two pistons through their respective rockers and connecting rods; this pressure causes a certain amount of friction on the special packing glands at the top of each cylinder, and the apparatus is thus rendered practically self-locking.

The spring in the receiver unit has also the function of exerting the operating force on the return or " suction " stroke, the design of the cam through which this force is applied to the rocker imparting a constant torque to the shaft. Owing to the cams, the springs in the transmitter and receiver units are always perfectly balanced by

each other at any position in their travel, and the control has therefore no tendency to move from its set position.

It will be seen from the illustration that the internal space containing the spring and rocker in the transmitter unit is used as a fluid reservoir, and is filled from an orifice in the cap; this fluid remains at atmospheric pressure.

The reservoir communicates with the base of the transmitter cylinder through a small port, closed by a spring-loaded valve. In normal operation this valve remains shut, but by moving the operating lever an additional five degrees at the end of the " suction " stroke, the valve is opened by means of a simple mechanical arrangement which will be clear from the figure; the system is now open to the reservoir, and any variations in the volume of fluid due to temperature change or slight seepage are automatically and instantaneously compensated for—a deficiency being made up or an excess driven out, and the transmitter and receiver restored to exact synchronisation.

The initial backward movement of the lever allows the valve to close once more, and any further movement will be exactly reproduced by an equal movement of the receiver.

Features of the Control

The Exactor Control system is accurate to a fraction of a degree. It is impossible for a backlash or lost motion to be present even after years of service. It is positive, will not vibrate from its exact position, and has a pleasant and constant " feel " throughout its range. Easily and rapidly installed, its only routine maintenance is the periodical topping up of the reservoir. Design costs are almost eliminated by the supply of so complete a control.

The total weight of transmitter and receiver units combined is five and a half pounds; to this must be added 12 ozs. per ten feet of $\frac{3}{16}$ inch O.D. copper pipe.

The fluid used is a mixture composed of 80° pure paraffin and 20° non-freezing oil (D.T.D.44/C, Intava " Utility " or Shell No. 1); these are almost universally obtainable. In special cases other oils may be used, if more convenient, subject to approval by the makers. In the event of pipe-line fracture the control will travel to a predetermined position which may, for instance, be arranged either to stop an engine or to give full power in accordance with requirements.

Typical Applications

The Exactor system provides an immediate and complete solution to the increasingly important problem of leading controls through the walls of an airtight cabin.

Its primary function is, perhaps, remote power control, and the best example of this is in aircraft or marine craft where two or more engines require careful synchronising from a central control position. Other purposes for which the control has been successfully employed in many aircraft are mixture control, constant speed airscrew control, oil cooler shutter, hot and cold air intake, slow running cutout, and landing lamps.

Capacity of the Control

On the return or " suction " stroke of the control, the load is operated by the energy stored in the receiver unit spring; in the standard control this spring will afford a constant torque of 120 lbs./inch, over the 60° arc of movement of the operating shaft. On the pressure stroke, very much larger loads may of course be transmitted.

The standard control is not generally used for runs of more than 100 feet, although satisfactory installations have in special cases been arranged up to 250 feet.

Although the control is self-locking up to a certain point, where the mechanism to be operated is fundamentally out of balance—as, for instance, in the case of a retractable landing-lamp which must be held out against the slip-stream—some simple form of ratchet gear is usually arranged at the transmitter lever. A range of standard designs is available.

Messier-Servo Hydraulic Jacks

The control of hydraulic jacks is generally effected by a distributor close to the pilot. When necessary an independent indicator is introduced to show the position of the jack piston rod during its operation. The stopping of the jack at a precise intermediate point requires careful attention and cannot be done with exactness if the speed of movement is great. Furthermore, to obtain accurate indication, complicated indicators must be used.

The Messier servo-jack enables the pilot to move the jack with certainty proportionately to the movement of the control lever.

Description

A small distributor is fitted to the end of the piston rod. The distributor has two valves, side by side—the one connecting the jack cylinder and the hydraulic pump—the other the jack cylinder and the tank. A single lever controls the opening of these valves and is adjusted so that one valve opens as the other closes. The lever is connected by some type of remote control to the quadrant in the cockpit.

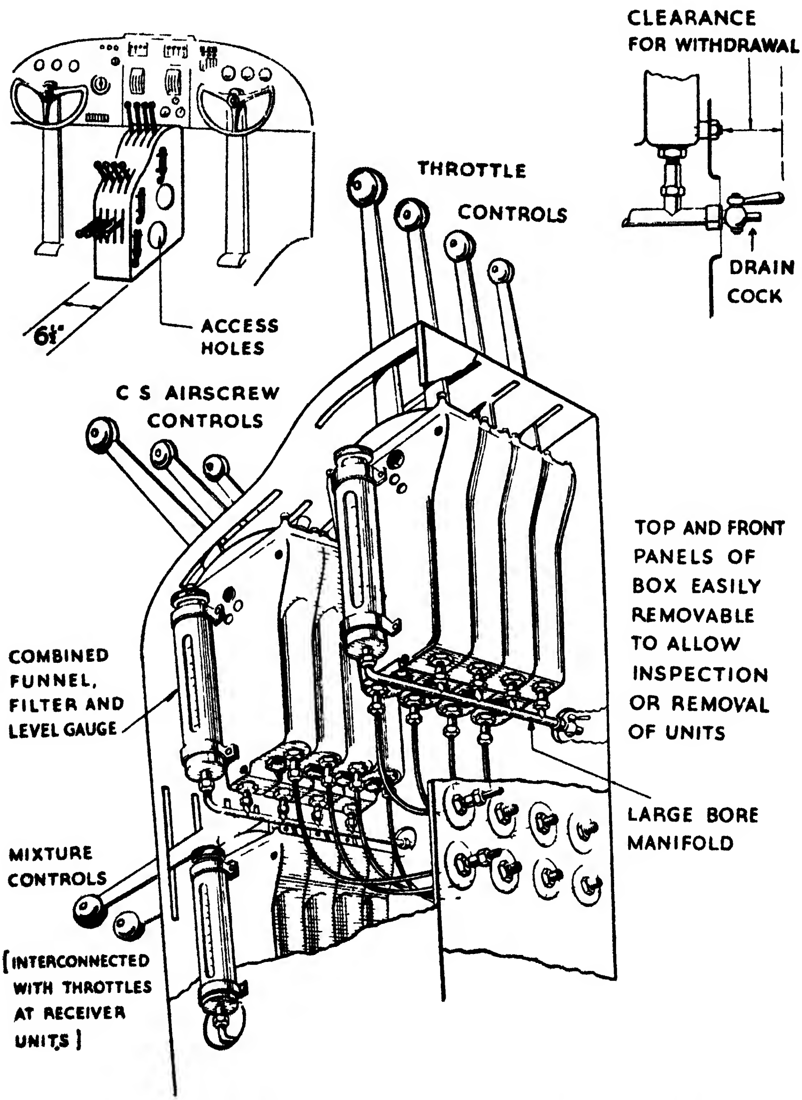


Fig. 314.—*Diagram of Exactor control installation on a heavy bomber.*

Operation

The pilot pushes his lever in the direction required : the corresponding valve opens and the distributor moves away with the jack. The jack moves as long as the pilot moves his lever and opens one of the valves. When the pilot stops his lever the jack continues to move until the distributor lever is drawn into the neutral position, thus stopping the action.

Advantages

An automatic and faithful duplication of the position of the lever.

Speed of movement under the control of the pilot.

" Pre-selection " not being possible, the pilot is completely confident of the position of the jack as indicated by his lever.

For the same reason a fault in the system is at once apparent to the pilot.

Simplicity of operation, there being only one control.

Remote Control Connection

A Messier irreversible hydraulic control completes the installation where the jack is at some distance from the pilot. The installation of the control is reduced to the fitting of two small pipe lines and the friction of the system to a negligible amount.

Saunders' Flying Control

This control comprises tubular push-pull control rods, to which a rotary motion can also be imparted. With this arrangement a single control run can be used to operate the two control surfaces separately or simultaneously without interference between the two elements.

Typical applications on larger aircraft are the aileron, or rudder, and their respective trimming tabs. In such cases, the push-pull movement would be used to operate the main control surface and the rotary movement to trim and set the tab. On smaller machines, an alternative installation can be provided where a single control run can be installed which will operate two main elements; for instance, elevator and rudder. The reciprocating action of the control mechanism secures positive and instant elevator response, whilst rotary movement of the same control provides equally positive rudder action.

With the long control runs necessary in multiple engine aircraft, it may be thought that the torsional deflection of the tube would result in too much flexibility when the rotary motion is being used, thus giving a flexible control. The possibility of this occurring has been overcome by incorporating into the system a 2 to 1 reduction gear-box. By incorporating this mechanism the applied torque loading is halved in the control tubes.

Maximum rigidity of the control is obtained by mounting it at specified minimum intervals in self-aligning stabilising bearings. With the spherical housings, deflections in the aircraft structure are accommodated, thus reducing friction in the control system to a minimum. To transmit the reciprocating motion to the control surfaces, links are provided at each end of the tube which are coupled to the crank of the cockpit control and the operating lever of the control surface. These links are attached to the tube by swivel housings, which permit the rods to turn freely when the rotary control is utilised.

Changes in the direction of the control runs up to an angle of 90° may be made by installing subsidiary gear boxes or universal joints. The maximum permissible change of direction the control run can make when utilising single universal joints is 15°. This must not be exceeded under any condition, owing to bending and side loads which are imposed on the control rods. A series of special adaptors are provided, such as simplified or flanged couplings, which can be readily incorporated in the control system for dismantling purposes or for fitting replacements, etc.

Adjustment needed between the cockpit control and the control surface is accommodated by standard double-ended screw adjusters. In addition, special fittings are also supplied for fitting dual control or automatic pilot. Control by rotary movement of the tube is transmitted through a gearbox, either main or auxiliary type.

The main gearbox, already described, incorporating the 2 to 1 reduction, is driven by bevel gears. These may be fitted either horizontally or vertically. Provision is made on the box for it to be readily assembled, either to port or starboard of the aircraft, and allows the square section shaft to pass through it.

The auxiliary gearbox is somewhat simpler and consists essentially of a sprocket and its mounting, the chain being used for rotating the sprocket and thus the squared section shaft, etc.

With these two gearboxes, motion can be transmitted to the control surfaces by chains, cables or rigid rods.

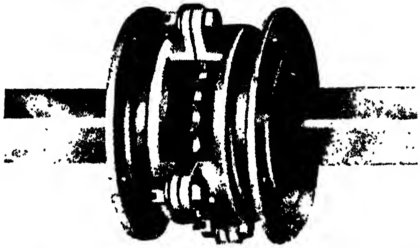


Fig. 315.—*Saunders auxiliary gearbox for transmitting motion through rotary movement of the control tube.*

The whole of the control system has been approved by the Air Ministry to stand a maximum factored load of 1,000 lbs. tension and compression. The torsional load is variable, dependent on the length of the control run. Working on a maximum load of 1,000 lbs., it is recommended that the stabilising bay lengths of the control members should not exceed 45 inches. Should the load exceed 1,000 lbs., the stabilising bay lengths can be reduced accordingly.

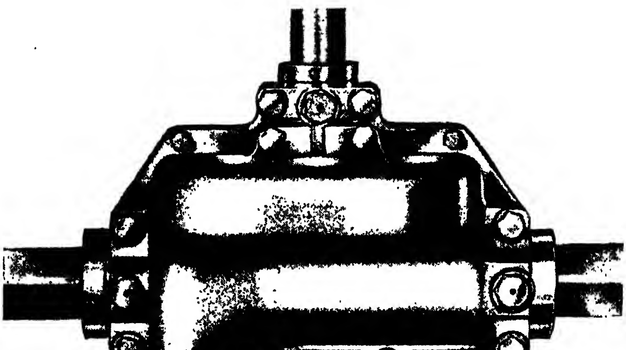


Fig. 316.—*Saunders main gearbox incorporates a bevel gear, giving a reduction of* 2 *to* 1.

Three different types of control tubes are employed on this control system, namely 1¼ inches by 20 S.W.G. aluminium alloy tube, 1¼ inches by 20 S.W.G. M.S. tube, or ⅞ inch 17 gauge M.S. tube.

A large number of standard fittings have been evolved, whereby it is possible for the Saunders Flying Control to be built up into practically any type of control run. In addition, it should be noted that the control system complies in its entirety to the requirements laid down in A.D.122.

Simmonds-Corsey Controls

The Simmonds-Corsey (patent) Control is accepted and approved by the British and many foreign Air Ministries as an efficient and reliable method of operating all types of flying and auxiliary controls for aircraft and is now standardised by over sixty aircraft manufacturers.

Among mechanical controls, the Simmonds-Corsey system stands in a class apart by reason of its combination of low back-lash and friction with ease of maintenance and inspection.

General Principle

The basic principle of the system comprises a series of olives and tubelets threaded alternately on a flexible steel cable. The olives have female hemispherical ends and the tubelets male hemispherical ends, so that a perfect ball-and-socket joint is obtained without either slackening or tightening of the cable as it bends. On each end of the cable itself a brass terminal, threaded externally, is secured and the complete linkage is then proof-loaded in tension. This requirement satisfied, the control is inserted in an outer casing tube of internal diameter very slightly greater than the external diameter of the olives. This tube, which is usually supplied in light alloy for aircraft use, can be bent to any desired shape within generous limits. The casing-tube may, if desired, be supplied in other materials, such as brass or steel. Finally, into each end of the casing-tube is inserted a rod or tube tapped internally to screw on to the brass terminal of the linkage, and finished off at the outer exposed end in any manner suited to connect up with the adjacent members of the control system.

Component Parts

The detailed components of the system are as follows :—

A. External circular casing tube in light alloy or other material, shaped as required to give appropriate run of control, and rigidly fixed.

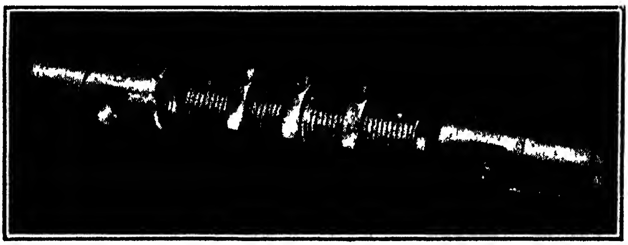


Fig. 317.—*A connector unit or union used for joining sections of the Saunders control tube.*

B. Olive in case-hardened steel, loosely threaded on special tinned steel cable and having hemispherical cavities at each end.

C. Tubelet in case-hardened steel with male hemispherical ends and of length varying with the radii of the bend of the casing tube, also threaded on the cable.

D. Terminal externally threaded and sweated or swaged on to the cable. In cases where the terminal is sweated to the cable, the terminal is of such a length that the shear strength of the sweating is equal to the tensile strength of the cable itself. At the inner end, each terminal forms a seat for the first tubelet of the linkage.

E. Sliding rods to link up with the adjacent parts of the control system. Where a rod is withdrawn to the full stroke, the portion remaining within the casing-tube must not be less than one-half of the stroke itself, in order to reduce wear in the casing-tube caused by bending moments.

F. Locking-barrel for the adjustment of linkage components.

G. Sliding inspection tubelet capable of being moved back over the terminal " H," and thus, by the sliding of successive olives and tubelets, permitting the whole of the internal cable to be inspected.

H. Terminal which enables the locking-barrel " F " to be screwed up against the sliding Tubelet " G " until there is no play between the elements of the linkage.

Applications

Simmonds-Corsey Controls are made in three sizes, No. 5, No. 7 and No. 10, these numbers being derived from the outside diameters of their respective casing-tube, expressed in sixteenths of an inch.

No. 5 may be used for indicators, light auxiliary controls, and controls of comparatively short length such as :-- -

Applications and details of each size are given below :—

Throttle and mixture controls for single-engined light aircraft.
Magneto controls.
Jettison valve controls.
Wheel brake controls.
Remote control for wireless and electrical service.
V.P. airscrew controls.
Bomb and torpedo release gear.
Locking gear for automatic slots.
Cockpit and cabin heater controls.
Flame trap controls.
Trimming tab controls.
Smoke apparatus.
No. 7. Longer auxiliary controls carrying larger loads, such as :—
Throttle and mixture controls.
Aileron, elevator and rudder controls on small aircraft.
Flap controls.
Fuel-cock controls.
Oil-cock controls.
V.P. airscrew controls.
Petrol pump controls.
Wheel brake controls.
Tail-skid steering controls.
Engine starting gear.
Swivelling landing-light controls.
Radiator shutter and flap controls.

No. 10. Flying controls, retractable undercarriage gear, and engine controls carrying heavy loads such as are met with in latest types of aero-engines.

Technical Data

In connection with the data given below, the following points should be noted :—

(i) The average weight is intended as a guide only, as considerable variation may occur due to the use of various types of end-fittings, or to the use of varying materials for these end-fittings.

(ii) Minimum radii permissible for bends have been given, but it should be borne in mind that as a general principle the radius of bends should be kept as large as possible with the object of bringing friction and back-lash to the lowest possible figure.

Control size	Nominal max. load in tension	Nominal max. load in compression	Av. weight per ft. run in light alloy	Min. radius of Bend	O/D of casing-tube	Thickness casing-tube	Nominal max. length of control
No. 5	100 lbs.	50 lbs.	1 oz.	3″	0.336″	18 S.W.G.	10′
No. 7	200 lbs.	100 lbs.	4 oz.	4″	0.438″	17 S.W.G.	12′
No. 10	400 lbs.	200 lbs.	8 oz.	4″	0.625″	17 S.W.G.	15′

AIRCRAFT INSTRUMENTS

The accuracy and length of life of aircraft instruments made in Great Britain set standards which are not surpassed by any other country in the world.

To some extent, this may be due to the craftsman's pride in an instrument designed and developed by the firm for which he works; and the names of some of the great instrument firms have come to be inevitably associated with particular types of aircraft instruments.

These include the Husun compasses; the Kelvin, Bottomley and Baird production of the sensitive three-needle altimeter; Negretti and Zambra development of the Bourdon tube instruments to provide mercury-in-steel thermometers in 1921, and transmitting pressure gauges operated by capsules in 1923, followed in 1927 by the boost gauge depending upon a stack of steel diaphragms; the Reid and Sigrist turn indicator; the extremely compact Simmonds free-float fuel contents gauge; Smith's Aircraft Instruments development, from motor-car practice, of the engine revolution indicator, followed by a host of other instruments illustrated in Fig. 318; and the Sperry directional gyro and artificial horizon.

Features of Husun Compass

These compasses have the new sylphon tube type of expansion chamber which is spun out of one piece of metal and provides efficient expansion over a much greater range of temperature than could normally be obtained.

The compensation is carried out by means of corrector boxes and not by loose detachable magnets which can so easily be lost.

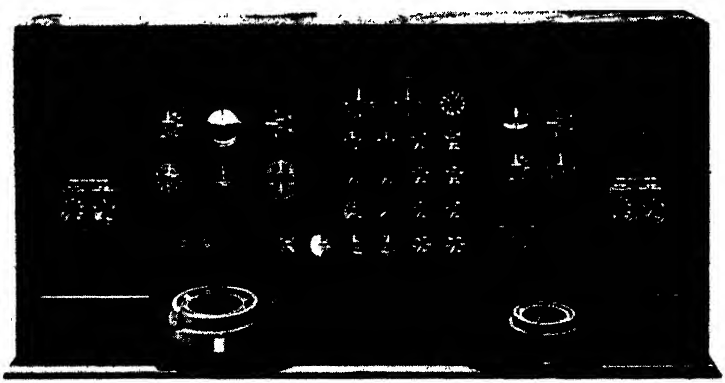


Fig. 318.—Set of Smith aircraft instruments and Husun compasses.

The filament damping provides for most efficient damping without setting up swirl in the liquid, so that the compass settles very quickly.

These compasses are also highly non-resonant, and any vibrations which happen to reach them produce the minimum of effect.

The very light weight of the magnetic element and a very high relative magnetic moment are of great assistance in producing the high standard of performance obtained in these compasses.

Grid steering, which obviates the necessity for the pilot to commit the course to steer to memory, was first introduced with these compasses. The high degree of aperiodicity to which the pilot compasses are constructed reduces the effect of northerly turning error to the greatest possible extent. This quality is of the greatest value in blind flying.

Installation of Husun Compass

The position in which the compass is to be installed should be considered most carefully, both from the point of view of the user's requirements and the conditions

governing the installation of compasses as a whole. Once decided, it should not be altered without reference to the competent authority.

No magnetic material, or instruments containing such, should be within 18 inches of the compass, and only non-magnetic materials may be used in the mounting, and securing bolts and nuts.

The compass proper is mounted in an outer casing by shock-absorbing devices, and there is a small amount of movement between the compass itself and its outer casing. During installation care must be taken to see that this small movement does not allow the compass proper to touch any part of the aeroplane structure under any conditions of movement.

The fore and aft line, marked on the casing in most cases, must be parallel to the fore and aft line of the aeroplane with the securing bolts or screws in the centre of their slots. Where such a line cannot be marked, as in the case of the P.7 type of compass, the back plate must be in a plane perpendicular to the fore and aft line of the aeroplane.

The surface to which the compass is secured must be perfectly level or vertical, as the case may be, when the aeroplane is placed in flying position.

When a separate corrector is used, it must be placed *centrally* below the compass at a suitable distance. If too close, it will be difficult to regulate the corrector owing to a small change producing too large an effect ; if too far away, it may not be possible to obtain sufficient correction.

Only the appropriate corrector should be used, the leaflets describing each type of compass stating that which is required.

K.B.B.—Kollsman Altimeters

For sensitivity to pressure changes, the Kollsman aneroid unit is unique, as is also the simple but highly efficient temperature compensation by means of which the readings of this instrument are rendered practically entirely independent of temperature variation.

With these as the fundamental features, mechanism of the very highest precision, but thoroughly robust and rigidly mounted, amplifies the original pressure-actuated movement of the "capsule," and transfers it to the pointers. So successfully is this amplification carried out and so free from friction and exact are the jewelled bearings, that the pointer traverses a circular scale 2½ inches in diameter for each 1,000 feet of altitude. This obviously permits of a very open scale, the smaller divisions of which represent 20 feet and make it easy to read to five feet or less.

An additional pointer, concentrically mounted, is fitted to the 20,000 foot instrument, and reads in units of 1,000 feet, and for the 35,000 foot instrument, a third pointer reads in units of 10,000 feet.

The dial being fixed, with the zero always at the top, this arrangement permits of the altimeter being read like a clock, and, with a little practice, altitude can be ascertained by a mere glance at the position of the pointers, without even reading the dial.

Owing to this marked accuracy and sensitivity, this instrument may, in addition to its ordinary function as an altimeter, be used as a level flight indicator—altitude variations of five feet or less being immediately apparent—and, in conjunction with a stop-watch, for the accurate determination of rate of climb or descent.

Means are provided whereby the instrument can be set with reference to any given barometric level. The object of this operation is that of adjusting the indication of the instrument to the barometric pressure at the point of reference, so that any discrepancy due to atmospheric conditions being other than standard is eliminated, the instrument thus indicating true altitude above the point of reference.

Negretti and Zambra Boost Gauge

The boost gauge or manifold pressure gauge indicates the absolute pressure in the induction pipe of supercharged aircraft engines. If the pressure is too low the power output is decreased, and if too high serious damage may be caused to the engine. The boost gauge is used to indicate when the recommended induction pipe pressure for maximum engine efficiency is attained at any altitude, its readings being unaffected by variations of atmospheric pressure.

The dial is arranged so that the indicated pressures are relative to that of the standard atmosphere at sea level. The latter pressure corresponds to "zero" on the dial, and when the engine is running, the pressure in the induction system is generally shown as pounds per sq. inch (or grams per sq. cm.) above or below normal atmospheric pressure. A "lubber mark" to indicate the maximum permissible boost is attached to the

underside of the cover glass, and can be set in the desired position when the bezel is unscrewed slightly. This can be done without breaking the instrument seal.

A single capsule, consisting of two hardened and tempered steel diaphragms with welded edges, operates the pointer, through a lever and quadrant-and-pinion mechanism. The tempered steel diaphragms employed give excellent pointer control, greatly reduce errors due to hysteresis, overload, shock, etc., and practically eliminate change of calibration with age. An important feature of this boost gauge is the elimination of a joint ring for the glass-to-case joint, enabling the airtightness of the case to be maintained indefinitely without attention.

The Reid and Sigrist Turn Indicator

This instrument was designed by a pilot—Squadron-Leader George Reid, A.F.C.—for pilots. As a means of saving life in conditions of " no visibility," it was selected by the Air Ministry to become the standard turn indicator on every British military aircraft. It has one needle to indicate sideslip and another for rate of turn. When the turn is correctly banked, the sideslip needle remains in the centre of the scale: that is, the effect of gravity on the sideslip pendulum is exactly balanced by the centri-

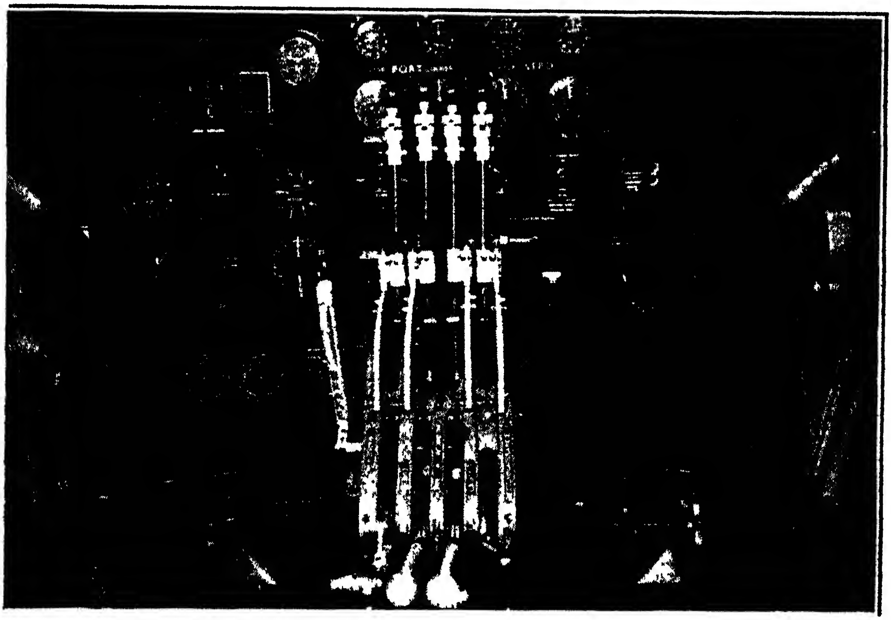


Fig. 319.—*Instrument layout in Stirling.*

fugal force of the turn, and there is no sideslip in or out. In the R.A.F. the " tightness " of a turn is still defined as Rate 1 or Rate 4 on the Reid and Sigrist turn and bank indicator.

Simmonds Free Float Contents Gauge

The Simmonds Free Float Contents Gauge has been designed with the object of combining in one instrument all the advantages separately available in gauges of conventional types.

No float arm or gearing is used, and there are only two moving parts. These are rigidly clamped except when the switch is pressed to take a reading. The float cannot move while a reading is being taken, consequently the reading is steady and unaffected by surging of the fuel.

Accuracy of indication is ensured by use of a resister strip equal in length to the tank depth. The space occupied in the tank is small; no baffles need to be cut and the tank

unit is very easily installed. The gauge is exceptionally robust, and the usual risk of damage during transport and installation is thereby minimised. The system requires only three wires.

The gauge entirely overcomes the well-known difficulty of installation in a tank of unusual cross-section, or one containing a number of baffles, since the whole unit is housed within a single vertical tube of less than three inches diameter. Moreover, practically the entire contents of a tank can be gauged without the necessity of providing pockets for the float at the top and bottom of the tank.

General Description

The complete equipment consists of four units :—

1. Tank unit.
2. Indicator.
3. Press-button switch.
4. Resistance unit—required on multi-gauge installations only.

A hollow metal float is firmly clamped between a resister on one side and a hinged metal bar—called the clamping bar—on the other side. The clamping bar is held in contact with the float by means of a spring, and an electro-magnet serves to pull the bar away from the float. Both the resister and the magnet are connected to an indicator through a press-button switch, and a battery is included in the circuit.

To obtain a reading of the level of the liquid it is only necessary to actuate the press-button switch. This is a double contact switch which acts in the following manner. Slight pressure energises the electro magnet which attracts the clamping bar away from the float, thus enabling it to attain the level of the liquid in the tank. Further pressure on the switch closes the second contact and breaks the magnetic circuit, so that the ball is firmly clamped once more.

Current then flows through the ball and resister back to the indicator, which gives a reading depending upon the length of the resister between the head of the gauge and the point of contact of the ball.

Smith Mechanical Engine Speed Indicator Mk. IX

The Engine Speed Indicator is fitted to aircraft to show the rate of revolution of the engine crank shaft. The Mk. IX indicator, used by the R.A.F., is a mechanical type incorporating a governor device. This device consists of a mass pivoted to the governor spindle, turning with it so that it tends to take up a position at right angles to the spindle under the influence of centrifugal force. The inclination of the mass to the spindle is controlled by a cylindrical spring, the amount then being dependent on the rate of revolution. The position of the mass relative to the governor spindle is shown by the indicator pointer, a precise mechanism being employed for this purpose.

The drive from the engine to the indicator is by means of a flexible shaft, which, in the case of British engines, usually revolves at one-quarter engine speed, although other ratios are available if required. The calibration of the shaft is always in terms of engine revolutions. In order that the forces acting on the governor may be sufficient for reliable operation, the latter is driven by gears so that it rotates at a higher speed than the incoming drive.

An advantage of a centrifugal instrument of this type is that the readings are independent of the direction of rotation of the governor.

Smith Electrical Engine Speed Indicator

Particularly suitable for aircraft with more than one engine, this instrument consists of two units : the transmitter and the indicator. The former is a small three-phase generator driven by the engine, and connected electrically by 3-core cable to the indicator, which comprises a motor-driven magnetic drag revolution indicator in one assembly. The motor runs in synchronism with the governor, and thus this electric coupling replaces the familiar flexible shaft in transmitting the drive from engine to pilot's instrument, without being subject to the same length limitations.

The indicator has two hands, one longer than the other and making one revolution of the dial per 1,000 r.p.m. The shorter turns at a tenth of this speed. The standard range of this equipment is 0 to 5,000 r.p.m.

The transmitter or generator is designed to receive the standard flexible shaft drive at a quarter of engine speed, and so it contains a 4/1 gearbox stepping up the drive to the rotor which thus runs at engine speed. The shafts and gears in this box are of generous section alloy steel, designed to give long service. The rotor shaft runs on ball bearings, and a seal is provided to exclude the grease packed in the gearbox.

The permanent magnet rotor turns within a laminated stator with a distributed winding of normal form giving an output of excellent wave shape and regulation. A robust, clearly marked terminal block with shrouded terminals is protected by a removable cover, and a standard cable anchorage completes the shielding.

The indicator motor comprises a small three-phase stator, and a salient-pole squirrel-cage rotor. On one end of and integral with this is the permanent magnet of the drag element, the whole revolving round a stationary shaft, passing right through the middle, and ending in a bearing for the drag element. Thus an overhung bearing for this is avoided, and extra freedom of movement and reliability ensured. The magnet of the drag element is thoroughly aged and stabilised. The drag element is geared to both fast and slow pointers, and so no difficulty arises from the restoring hair-spring even at maximum r.p.m. The terminal arrangements are similar to those on the generator. If desired two indicators can be operated in parallel off one generator.

Smith Airspeed Indicator

The Airspeed Indicator has to fulfil important functions, particularly those in which it is used as a member of the primary flight group, and those which concern navigation problems. It must show the slightest of variations in speed and be accurate.

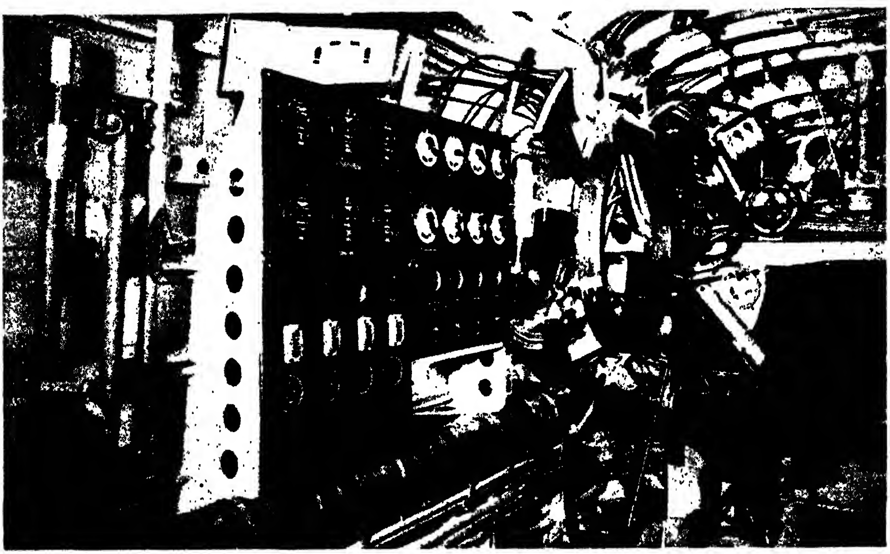


Fig. 320.—Flight engineer's control station in Stirling.

The instrument described is a delicate differential pressure gauge which measures the difference between the dynamic and static pressures of the air as produced by a pitot tube (or pressure head) mounted in such a position that it is not affected by the airstream over the structure of the aircraft.

The instrument case itself is airtight and is connected to the static side of the pressure head, whilst the dynamic or impact pressure is applied to the inside of a flexible capsule mounted in the case. The dynamic pressure causes the capsule to expand, its movements being converted into rotation of a pointer through the medium of a suitable mechanism. This mechanism is designed to compensate for the square law relationship between airspeed and pressure difference as produced by the pressure head. The instrument consequently has a substantially uniform scale.

The construction of the instrument conforms to the requirements of the relative British Air Ministry specification. It is built in a moulded case, the glass being screwed down by a moulded bezel on to suitable packing rings which ensure a static-tight joint. The connections are clearly marked. The diaphragm, which is formed of carefully

chosen material, is provided with a stop to prevent damage by overload conditions, and the connection between the diaphragm and the pressure nipple has a restriction which damps any oscillation of the pointer induced by pulsations or rapid pressure changes. The mechanism is accurately made and incorporates means for temperature compensation.

It is intended that the instrument be mounted on the instrument board in the ordinary way, and its size, the dimensions of the necessary cut-out, and the position and size of the fixing holes are specially arranged accordingly. Before fitting the instrument to the panel, a double run of aluminium tube $\frac{5}{16}$ inch by $\frac{1}{4}$ inch should be taken to the pressure head, and this should be blown through before the instrument is connected to make sure that it is clear. When installing these tubes, sharp bends and flattening must be avoided, neither must there be any U-bends in which water could collect. The nipple marked " P " is joined to the pressure connection of the pressure head, and that bearing the letter " S " to the static tube.

Smith Electrically Heated Pressure Heads

Pressure heads of all types provide the reference pressures to operate the airspeed and rate of climb indicators, and the altimeter. These instruments are of great importance to the pilot when flying under normal conditions, but it is absolutely essential that they should function correctly when he meets bad weather or is compelled to fly "blind." It is when these conditions are met that the danger of ice formation on propellers, leading edges or any part of the structure which meets the airstream arises.

The early stages of ice formation on the pressure head will cause erroneous readings of the indicators, particularly in the case of the airspeed indicator. Finally, the tube becomes completely blocked, and the instruments will cease to function at a time when the pilot most needs them.

It has become necessary, therefore, to redesign the pressure head to incorporate an electric heater, the action of which will prevent the formation of ice.

The " pressure " aperture is in the spherical end and incorporates a water trap and drain hole through which any water which may enter can pass away. Static pressure is communicated through slots in the side, connections being brought out to clearly marked unions.

A special material with a large temperature coefficient of resistance is used for the heater element. This results in more energy being used when cold, the current being reduced as the temperature rises. Damage due to overheating, therefore, is prevented should the supply be left switched on when the aircraft is on the ground.

Whether for leading edge or under wing installation, both types of head are of simple construction and have a substantial body for installation purposes. This contains the terminal block from which the connections are led off. It is also screwed to receive the outer tube of the pressure head, which slides over a distance piece separating the heater compartment from the static chamber.

The heater itself is in a monel metal sheath which maintains the insulation value even under conditions of driving rain. A failure of the element is unlikely, but should one occur the heater is readily replaceable. The ends of the heater are brought to a terminal block, where they are joined to the 6-foot length of twin lead which is normally fitted. The energy consumption is approximately 75 watts in either the 12 or 24 volt type, resulting in an adequate temperature rise.

Avimo Pressure Heads

Two types of pressure head are manufactured, one type being suitable for fixing to the leading edge of the wing, and the other type is for under-wing fixing.

Both types of head are of simple construction and have a standard spigot for attachment to bracket on aircraft. The tubes, heating element and electrical circuit form a complete sealed assembly which presents a smooth streamline exterior. Servicing requirements call for no dismantling and it is not possible to take the head to pieces without damaging essential parts. The pressure and static connections are led out through the securing spigot and are plainly marked " P " and " S " respectively; each connection is provided with a standard screw union end, suitable for the pipe lines leading to the indicating instruments. The double electric cable is also passed through the securing spigot; a suitable length of double cable is supplied with each head.

To remove surplus water or melted ice, and to keep the pipe lines dry, drain holes and baffles are arranged internally. The pressure tube has a baffle, and immediately in front of this is a small drain hole which allows water to drain into the static tube.

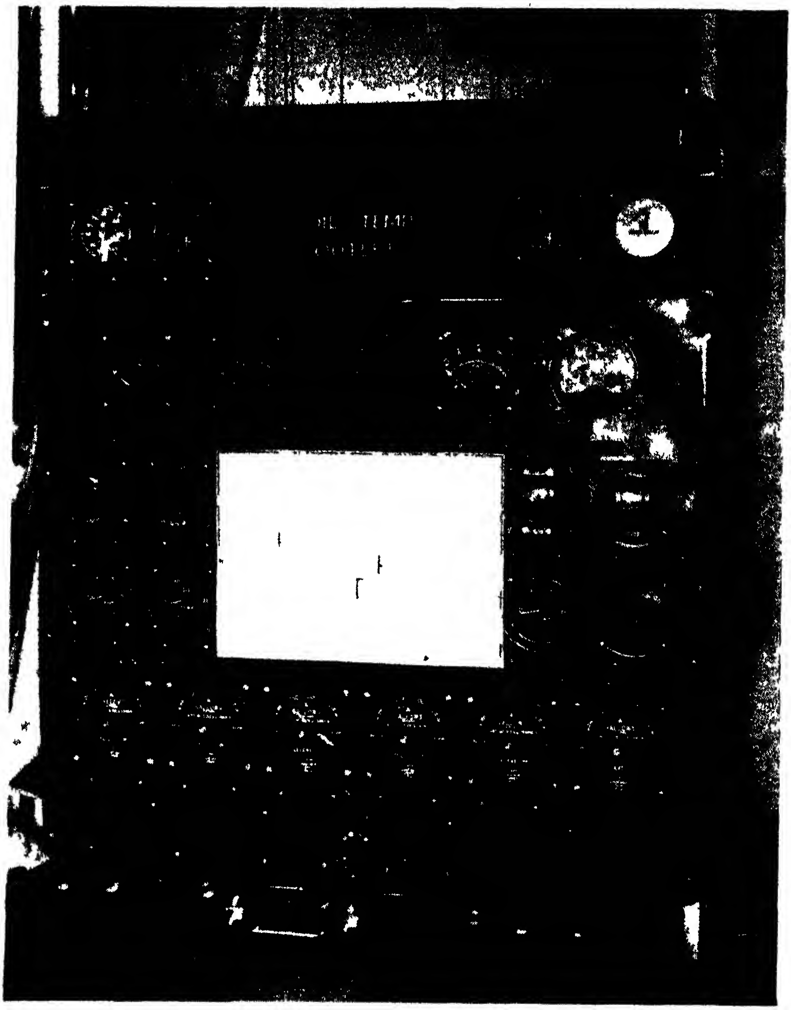


Fig. 321.—Engineer's panel on Sunderland, fuel cock control levers below.

The static tube in turn is drained by arranging one of the transverse slots to be at the bottom of the tube, and also by a small hole drilled in the bottom of the tube in line with the static pipe connection through which rain that might enter by the static slots is drained off when the pressure head is inclined owing to the aircraft being on the ground.

It might be considered that this connection between impact and static tubes would upset readings, but wind tunnel tests have shown that if the cross sectional area of this drain hole does not exceed a certain fraction of the cross-sectional area of the impact pressure tube, the effect of this "leak" in impact pressure has a negligible effect on the accuracy of the readings. Locking devices are provided for all screws and connections.

Sperry Artificial Horizon and Directional Gyro

All R.A.F. aircraft are equipped with the Blind Flying Panel, carrying on anti-vibration mountings those instruments which are vitally necessary in conditions of bad visibility. The Sperry Directional Gyro and Artificial Horizon are two of the six instruments on the panel, and occupy the central position.

Unless he can use his sense of vision to determine his attitude with respect to the horizon, the pilot's sense of balance is confused and his special orientation is inaccurate, Even birds, when blindfolded and released, are unable to continue flying normally but will flutter to the ground in a manner entirely foreign to natural flight.

As the natural horizon is the reference which a pilot instinctively uses, the Sperry-Horizon was designed for use as a substitute when the natural horizon is obscured. It responds instantly, requires no interpretation, and provides a guide upon which the pilot may instinctively and naturally depend.

It is impossible to fly " blind " with the magnetic compass unless the aeroplane is flying absolutely straight. The slightest turn of the aeroplane tilts the compass card, and the vertical components of the earth's magnetic field, acting on the needles, gives the card a swing, setting up an oscillation which does not disappear until after the aeroplane has resumed a straight course. To attempt to fly the aeroplane by the magnetic compass alone is a case of " the blind leading the blind."

In general, the practice with the magnetic compass is to steady the aeroplane near the desired compass heading, wait until the compass card has come to rest, and then attempt to correct for any discrepancy. This procedure involves exterior marks or the use of some gyroscopic turn index; for magnetic compass oscillations will not damp out as long as the aeroplane is moving in azimuth.

If the magnetic compass could be held stable in azimuth the problem would become simple and a desired course could be set and maintained by keeping the lubber line opposite the desired heading. The Sperry Directional Gyro allows this method of course-keeping and flying to be employed. It therefore combines the most desirable qualities of a flight control instrument for aerial navigation.

Silentbloc Anti-vibration Mountings

In the construction of these mountings two pressings are spot-welded together and grip the outer rim of a rubber diaphragm, the shape of which is the subject of a patent. A sleeve with flanged ends is held in the centre of the rubber and through this sleeve passes the bolt holding the body to be mounted. The pressings are of various types and may be attached to the support in different ways.

An important feature of Silentbloc mountings is that they are cadmium plated as a preventative against rust and corrosion. This is the standard finish, but certain other finishes can be supplied, and for special purposes the metal parts, which normally are made in steel to Air Ministry specification, can be made of non-magnetic material.

In the development of standard sizes it was found desirable to adopt a scheme of rating in which the load required to give a certain deflection increased by regular amounts throughout the range. The standard deflection is $\frac{1}{16}$ inch, and the load required to deflect any mounting to this extent is indicated by the figure in the part number. This figure does not necessarily represent the maximum load which can be carried by the mounting. Most mountings may be deflected up to $\frac{1}{8}$ inch, and this fact is frequently of great assistance to designers when space is an important consideration. If still higher deflections are required the mountings may be arranged in series.

Choice of Suitable Type

The size of the mounting for any particular application is determined by two principal factors. These are the load to be supported and the exciting frequency. It is not always easy to fix a value for the latter, as many disturbing factors may exist, but it is usually safe to assume that it is some function of the engine speed. In aircraft instrument boards the fundamental frequency of vibration is often equal to the engine speed and, in the absence of any definite information to the contrary, calculations may be based on this assumption. In any case, should the frequency be two or three times engine speed, the effect is simply that the same mountings give a decreased " magnification factor " or damping ratio and thus the mountings are more efficient.

The " magnification factor " is a measure of the transmissibility of the mounting. When the disturbing frequency is small compared with the natural frequency the magnification factor approaches unity. As the disturbing frequency increases with relation to the natural frequency the value of the factor increases rapidly until, when

the two frequencies are equal, resonance occurs and the factor is theoretically infinitely large. Actually, damping has an appreciable influence at or near resonance and the amplitude of vibration is kept within finite limits. As the disturbing frequency continues to increase, its ratio to the natural frequency of the mounted apparatus becomes larger, and the value of the magnification factor decreases; for very high values of the ratio the mounted body can be considered as stationary. This is the condition which is aimed at with all mountings designed to prevent the transmission of vibration. In selecting a suitable size for the mounting we must, therefore, choose one which will (*a*) carry the load imposed upon it; (*b*) deflect under that load to such an extent that the mounted frequency is as low as possible.

In practice it is not possible to reduce the transmission to zero and authorities vary in their estimates of what can be considered a reasonable figure for satisfactory results. In the case of instrument mounting it is desirable that the amplitude of vibration should not exceed .004 inch, and this figure can often be reached with a magnification factor of as much as ⅛. This means that the ratio of disturbing frequency to natural frequency may be as low as 3 : 1. It is usual to work to higher figures than this and ratios of 5 : 1 and 7 : 1 are common. These ratios give magnification factors of 1/24 and 1/48 respectively, and the second figure may be regarded as really good cushioning.

The mountings provide a neat and easy method of supporting instruments, instrument panels and so on. Loads ranging from ¼ lb. to 45 lb. can be carried on a single mounting and any required deflection can be obtained. Where it is required to support still greater loads, reference should be made to the makers, who produce Silentbloc mountings which will carry loads up to 2,000 lb.

Examples of Mounting Applications

As an instance of the use of two mountings in series, the "blind flying" panel may have to be mounted separately from the main instrument panel and has, of course, to be mounted vertically, whereas the main panel is at an angle. The panel is supported from a cross tube, and one of the advantages of the method used is that the panel may be tilted forward, turning about the centre of the mounting so that access may be gained to the backs of the instruments. The mounting consists of a rubber bush inserted in a metal pressing and having a metal centre sleeve, but the load is applied at right angles to the axis, instead of along the axis as in other anti-vibration mountings. The mounting is, in effect, a special form of the well-known flexible bearing made under Silentbloc patents, that is to say that the rubber grips the inner and outer sleeves by virtue of its initial loading, and any movement such as occurs when the panel is tilted forward takes place by stretching the rubber.

Other types of Silentbloc mountings are used for tank installation.

AUTOMATIC PILOTS

The Smith Automatic Pilot

THE Smith Automatic Pilot is intended to relieve the pilot of an aircraft from the monotonous duties of piloting on long flights or under bad weather conditions, and since it is able to control the aircraft with much greater accuracy than the most skilled human pilot, its use is conducive to greater safety and economy as well as enabling the pilot to devote his almost undivided attention to the important duties of navigation.

Provided that a machine is fitted with a suitable equipment of instruments for blind flying, a skilled pilot can fly an aeroplane in almost any weather conditions, but the physical and mental strain of flying in bad conditions with poor visibility is considerable, and when, in addition, the pilot is faced with the task of navigating the craft to its destination, the risk of disaster can become very serious. By the use of the Automatic Pilot, the pilot is relieved of his ordinary work of controlling the aircraft and he can devote himself to the work of navigation or to the operation of the radio equipment, and thus, under bad weather conditions, a far higher standard of safety is ensured.

It is important to stress, however, that the Automatic Pilot is not just a "gadget" intended to relieve the pilot of his normal duties. It is not a mere "blind-flying instrument" adapted to the control of the aircraft, but is a mechanism of the highest reliability and precision, and although its more general use is for the control of an aircraft on ordinary commercial routes, its great accuracy renders it of invaluable service for such work as aerial survey by photography or for precision bombing.

An aircraft controlled by the Smith Automatic Pilot will seldom deviate from its course by more than 4° or 5° in an hour, and there is thus not the slightest necessity for frequent checking of the course by reference to the magnetic compass.

The Smith Automatic Pilot depends for its operation on two gyroscopes which are driven by compressed air at a pressure of 35 lbs./sq. inch. Unlike other automatic pilots, the system operates by compressed air throughout and not only does this tend towards lower weight, but in addition much greater reliability is obtained, since delicate pneumatic-hydraulic relays are rendered unnecessary and the inevitable troubles due to changes of viscosity and leakage of oil are avoided altogether. Furthermore, the direct operation of the servo-motors by compressed air results in an important reduction in the lag of the controls. A reduction of the servo-motor lag is of vital importance since far better damping of aircraft oscillations is thereby obtained.

In order to understand the elementary principles of the Automatic Pilot, it need only be remembered that a gyroscope (which consists of a "flywheel" rotating at high speed in a special form of mounting) possesses the property of tending to maintain its axis fixed in a given direction. A perfectly balanced and freely supported gyroscope spinning at high speed will in fact maintain the line of its axis fixed directionally almost indefinitely, no matter how the mounting itself may be moved.

Suppose that such a gyroscope is installed in an aircraft, then whatever direction the aircraft may take or however disturbed the weather conditions may be, the axis of the gyroscope will continue to point in the same direction as when it was started. If the aircraft should deviate from its steady course, the angle through which it has turned can be readily ascertained by reference to the gyroscope.

In the Smith Automatic Pilot, the gyroscope which controls the rudder is installed so that normally its axis lies fore-and-aft in the aircraft.

If the aircraft should deviate from its course the axis of the gyroscope will no longer lie fore-and-aft in the machine, and this departure actuates a small air valve which is so arranged that it causes the aircraft rudder to be applied through the agency of a "servo-motor" in order to correct the deviation.

The same gyroscope is used to control the elevators of the aircraft when a pitch disturbance occurs, but a second gyroscope is employed to control the ailerons. As in the case of the rudder control, deviations of the aircraft in pitch and roll operate small air valves which control the movements of the appropriate aircraft controls. The sensitivity of these valves is such that a deviation of the aircraft of about a tenth of a degree is sufficient to cause a correcting movement of the appropriate control.

A further important factor is that the magnitude of the movements of the aircraft control surfaces is arranged to be proportional to the magnitude of the deviation. Thus, a minute deviation results in a similarly minute movement of the controls, while a large deviation results in a proportionally greater correcting movement. As the deviation is corrected, however, and the aircraft gradually returns to its course, the correcting movement of the control surface is progressively reduced and thus all harshness and over-correction are avoided. The pneumatic system employed is ideal for the control of these small movements and cannot be rivalled by any other system.

The main gyroscopic units of the Smith Automatic Pilot are installed in almost any convenient position in the aircraft (e.g., under the pilot's seat), and controlled from the pilot's cockpit. This arrangement was adopted because it was felt desirable that entirely independent means should be provided to insure against the failure of any piece of equipment essential to the safety of the aircraft. By installing the automatic pilot in some other part of the aircraft, an entirely independent set of normal "blind-flying" instruments can be installed in the dashboard for use in the event of a failure of the automatic pilot.

Furthermore, the arrangement of the Smith Automatic Pilot enables it to be installed in almost any aircraft without the necessity for a specially designed layout or the construction of a special instrument panel, and it possesses the added advantage that the design of the gyroscopic apparatus is not unduly restricted by considerations of space. The designer is, therefore, free to adopt a form of construction and to employ gyroscopes of sufficient size to ensure the utmost reliability and accuracy.

The pilot is provided with a Main Control Cock for bringing the Automatic Pilot into action, and he is also provided with certain additional controls for executing turns while under automatic control and for varying the pitch attitude which he is able to adjust between the limits of 5° climb and 10° dive. The operation of these controls is such that the transitions are smooth and gentle, even if the control lever is moved suddenly from one extreme position to the other.

In addition to these controls, a lever is provided by which all three of the servo-motors may be mechanically disconnected from the aircraft controls in an emergency, for example, if a vital part of the pneumatic system or a servo-motor were damaged by a bullet.

The whole system is operated by a compressed air supply provided by a small and light compressor which may be driven either by the engine or by a windmill, as desired by the operator. The design of the compressor system is such that a trace of oil vapour becomes mixed with the compressed air and serves to maintain continual lubrication to all the moving parts. An air drier, containing Silica Gel, is also provided to guard against the risk of ice forming anywhere in the system when the weather conditions are such that ice formation is a possibility.

The Sperry Gyropilot

By assuming the burden of actually flying the aircraft, the Gyropilot makes it possible for the captain of the aircraft to devote his entire attention to observation, navigation, radio, engine control and, in fact, general supervision of the aircraft, and the flight. With the Gyropilot in control, long flights can be made, even in bad weather, with a high degree of precision.

From the point of view of comfort, the Gyropilot is equally desirable. It detects the slightest departure of the aircraft from its proper course and attitude, and acts simultaneously to apply corrective movements of the controls. Thus, in rough air the aircraft is not subjected to the larger angular displacements resulting from delayed manual control and the passengers are conscious of a sense of stability and security which would otherwise be lacking.

The Sperry Gyropilot controls the aircraft about all three of the axes of angular motion—lateral, longitudinal and directional. It is flexible in operation, permitting normal manœuvres to be made under Gyropilot control.

Its action, based on pneumatic and hydraulic principles, ensures smooth, positive operation of the control surfaces of the aircraft.

It may be adjusted instantly while in flight to ensure the most desirable operation for any air conditions.

The Sperry-Horizon and the Directional Gyro were designed for blind flying and the Gyropilot was developed from them. These instruments provide the pilot with a true picture of the attitude of the aircraft. The Directional Gyro is an accurate index of turn which neither lags nor oscillates and is unaffected by rough air or magnetic disturbances. The Sperry-Horizon shows the pilot when flying blind what he could see if he could see outside the cockpit, i.e., the angular position of the aeroplane in relation to the horizon. Both have proved to be of vital importance in bad-weather flying. Dials similar to the dials of the separate instruments are contained in the Gyropilot control units, and these are mounted on the instrument board, so that the pilot is provided with a continuous indication of the course and attitude of the aircraft whether it is being flown by Gyropilot or by manual control.

The Directional Gyro Control Unit

This unit contains the Directional Gyro which is a directional reference for both manual and automatic steering control. It also contains a ball bank indicator, the air pick-offs and follow-up mechanism for directional control, and a means for setting the Gyropilot to steer any selected heading. The Directional Gyro Control Unit, together with the Bank and Climb Gyro Control Unit, is carried in the Mounting Unit and the whole is installed as a part of the instrument panel.

The Bank and Climb Gyro Control Unit

This unit contains the Bank and Climb Gyro which is used for lateral and longitudinal indication and control, and the level flight control. It also contains the air pick-offs, together with the means for making manual adjustments. The aileron knob permits one set of pick-offs to be adjusted for the desired lateral attitude, and the elevator knob controls the setting of the other pick-offs for longitudinal control. Follow-up indices show the lateral and longitudinal settings which are made. The Level control sets the Gyropilot to fly the aircraft at the desired altitude. The Bank and Climb Gyro Control Unit is carried next to the Directional Gyro Control Unit in the Mounting Unit.

The Mounting Unit

The ease of maintenance of the Gyropilot has been carefully planned. The Mounting Unit is provided with tracks on which the Control Units slide into place;

where they are secured by four attaching bolts. Air, follow-up and lighting connections are made automatically when the bolts are tightened and disengaged when the Control Units are withdrawn. Either of the two Control Units can thus be replaced in a few minutes.

Other component parts which are carried on the Mounting Unit, such as the balanced oil valves, the air relays and the follow-up pulleys, are easily adjusted in place or can be removed for inspection and servicing without having to disturb the rest of the equipment in any way. Standardised parts and the accessibility of the various units help to keep maintenance costs to a minimum.

How the Gyropilot is Used

As soon as the aircraft is clear of the aerodrome and on its course, the captain rotates the adjusting knobs on the Gyropilot control unit so that the three follow-up indicators match the gyro indications for direction, bank and climb. Then he moves the engaging lever slowly to the " on " position. The elevator knob is adjusted to obtain the desired rate of climb. Once this is set, the aircraft continues climbing steadily until the cruising altitude is reached, at which time another slight turn of the elevator knob puts the aircraft in level flight.

If a small course change is desired, it is only necessary to rotate the turn knob slowly to the right or left. Continuous banked turns may be made by caging the Directional Unit and applying bank with the aileron knob. When flying in co-operation with the radio beam the precision with which these small changes in heading can be made while the Gyropilot is in operation is an important factor in keeping the aircraft on course.

A slight turn of the knob is all that is necessary for the Gyropilot to maintain a steady rate of descent until the captain is ready to take over the controls, and make his landing.

To disengage the Gyropilot, the captain takes over the controls and moves the engaging lever " off." In an emergency he can overpower the Gyropilot while it is in operation.

AIRCRAFT HEATING

Features of the System

Any system of aircraft heating must be light in weight, safe and trouble-free in operation, and the problem can be approached in a number of different ways. In the Gallay system the heating is combined with an air-circulation system. The complete equipment comprises three main units: the boiler, the heater unit, and the header or pressure tank, which is mounted on the fireproof engine bulkhead.

The Boiler and Heater Unit on Wellington

The boiler is of the flash type, and is mounted in the exhaust system of the port engine. Steam generated in the boiler passes to the heater unit situated in the supply ducting from the air intake. The heater unit is a radiator of a special type having a very high thermal ratio, the tubes of which are heated internally by the steam. In warming the incoming air stream these tubes give up their heat, and the steam is condensed and returned to the boiler.

Supply from Header Tank

The system is self-regulating, and, theoretically, should continue to operate indefinitely without need of replenishment. In practice, of course, losses occur through successive condensations. As long as a sufficient pressure of steam is maintained, the system makes no demands upon the reserve supply in the header tank. If the pressure should drop, however, water is automatically fed to the boiler from this source. A safety valve is fitted on the steam pipe between the boiler and the heater unit. Water is introduced through a filler at the heater end of the same pipe. Distilled water is used, the capacity of the system being 1½ gallons. Under running conditions the pressure tank is only partially filled with water, and the air in the upper part acts as a cushion which assists in regulating the pressure in the system and in supplying water to the boiler. One of the advantages of a steam-operated system is that there is no danger of poisoning from carbon-monoxide gas.

Installation

The air intake is built into the leading edge of the wing, and is coupled to the heater by a light alloy duct From the outlet side of the heater a system of ducting extends through the fuselage of the aircraft, branches being taken off at suitable points to supply the individual members of the crew with warmed air When the installation is being laid out, a full size mock up of the ducting is constructed, and test readings are taken at each outlet to ensure that the warmed air is evenly distributed, and that an adequate supply is received at each point Apart from the outlets which are arranged to serve each member of the crew, there is a general supply to the rear cabin and a separate connection to the camera By means of a flexible pipe, warmed air can also be supplied to the sleeping bunk or to the astral dome A butterfly valve is fitted in the main ducting close to the heater outlet By operating a control inside the fuselage this valve can be set to regulate the admission of heated air to the interior of the aircraft, or, if desired, to cut it off completely and discharge it into the open air There is also independent control at each station, with the exception of those in the rear cabin, and at the camera and sleeping bunk

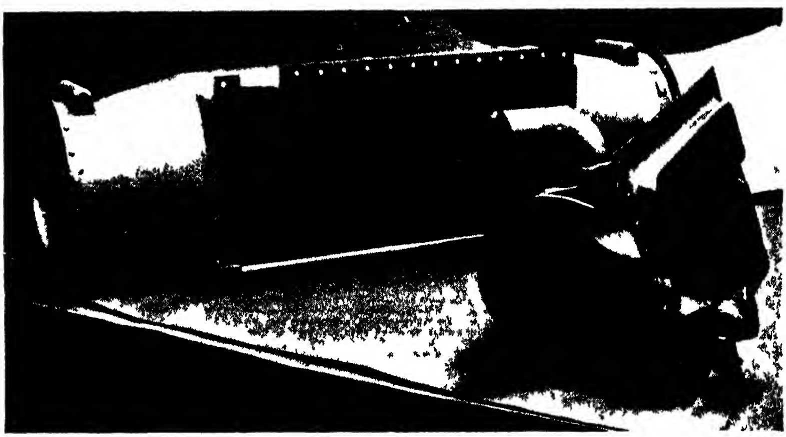


Fig 322 —*Parts of Gallay Boiler*

TRANSPARENT ENCLOSURES FOR AIRCRAFT

Streamline Shapes

The high speed required from modern military aircraft has brought with it the double necessity of enclosing the crew and of reducing air-resistance by fairing in all apertures to as close an approximation of the ideal streamline form as possible. For the curved portions of such enclosures the acrylic-resin plastics have been developed, and in this country, Perspex, the product of Imperial Chemical Industries, Ltd., is largely used Panels of laminated glass are employed also for a number of purposes, such as bomb-aimers' windows and, as a protective measure, for sighting panels in fighter aircraft.

British Indestructo Glass, Ltd , well known as manufacturers of safety-glass windscreens for cars, are now engaged in the manufacture of all types of transparencies for aircraft in Perspex, cellulose-acetate, and laminated glass. On the plastic side Perspex and acetate turret-panels are being made, and the firm also fits and assembles these to the complete turret frame. Other plastic components include wing-tiplamp fairings, cabin hoodings, and blisters of deep and compound curvature for bomber aircraft.

Advantages of Perspex

With a specific gravity of 1 9 as compared with 1 35 for safety celluloids and upwards of 2 5 for glass, Perspex has what is claimed to be the lightest weight of any of the transparent materials in common use This advantage is combined with light-transmission qualities considerably higher than those of the best optical glass, and these properties are retained in sunlight and under conditions of high ultra-violet intensity It has good dimensional stability and, when suitably fitted, does not warp or shrink with age or as a result of being exposed to varying atmospheric conditions

Perspex has good mechanical properties at low temperatures, and both impact and tensile strength increase as the temperature decreases De-icing fluids to specifications DTD 344, or DTD 406A for airscrews and windscreens respectively do not attack it or affect it in any way

Working of Perspex

As supplied to the manipulators by I C I, Ltd, Perspex is in the form of flat sheets protected from accidental scratching by white paper attached to the surface by gelatine. During the initial operations of marking out and trimming, this paper is left in position The panels are marked out to a template and cut roughly to size on a high-speed Walker-Turner band-sawing machine A good edge finish is obtained by cutting Perspex dry on machines of this type An improvement can, however, be obtained by using water as a lubricant On the initial trimming operation excess material is left all round for subsequent removal after forming

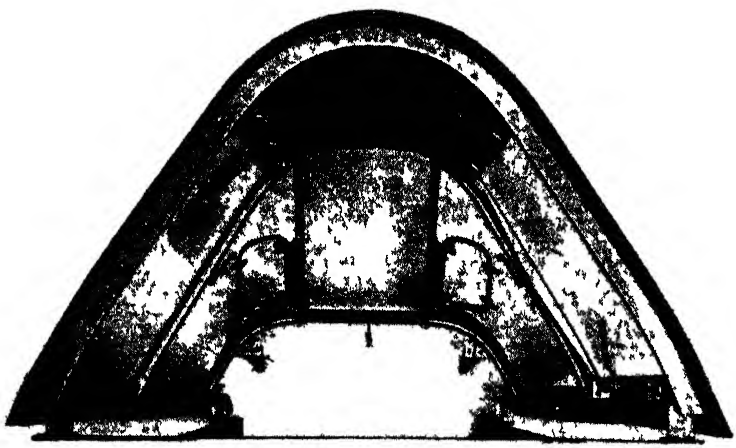


Fig 323 —Beaufighter Windscreen, by Weathershields, Ltd.

In drilling Perspex care has to be taken that too great a pressure is not applied, as otherwise the panel may split By maintaining steady pressure, however, and allowing the tool to cut its own way through, the material can be drilled without difficulty. Standard twist drills are used, but as an additional precaution against the splitting of the sheet as the drill breaks through, the cutting angle is reduced by grinding the point rather flat. The best cutting speed is about 2,400 r p m for a $\frac{1}{16}$ inch diameter drill.

After being drilled the panel is removed from the turret frame and cleaned, all swarf and dust being removed. To give a watertight joint Bostik B plastic rubber compound is applied to the faces of the turret ribs before the panels are finally assembled. It is allowed to set for a period of twenty-four hours. Countersunk-headed screws, secured by self-locking nuts on the inside, are used to attach the panels to the ribs of the turret frames.

Handling Perspex

In handling Perspex the difficulties of preserving an undamaged surface free from scratches or blemishes are added to the actual problem of manipulation. The surface of the material has a hardness comparable with that of aluminium, but owing to its transparent nature, even slight scratches show up very clearly. With flat sheets, which require only trimming to shape, it is possible to retain the paper covering throughout. In the case of formed panels, however, this is obviously impossible and the masking of the sheet after forming would probably take longer to accomplish than the remaining forming operations. Extreme care is necessary at all stages. Shallow scratches can be removed by buffing or polishing, but this again requires expert manipulation, as otherwise a depression or wave may be made in the surface, with consequent impairment of the clarity of vision. To provide a protective coating during processing, experiments are being made in spraying the surface of the material with rubber.

Laminated Glass

As specialists over a long period in the production of laminated glass, the British Indestructo Company has initiated some interesting developments in this field in the belief that the post-war development of civil aircraft will create a large demand for this material owing to its durability and excellent appearance. A number of units of a type formerly produced only from plastic materials can now be obtained in laminated glass. Laminated glass panels, whether flat or curved, pass through the same general sequence of operations. At first they are trimmed to shape. Where small quantities only are involved, this is done by laying a template of the required shape on a sheet of glass and passing a diamond cutter round it. For large quantities and for mass production a pantograph type of machine is employed, in which a template controls the movement of the head and traces out the required form on the glass sheet. In both cases cutting is followed by a trimming operation, after which the panels are inspected and passed on for cleaning prior to compounding and bonding.

Bullet-Proof Windscreens for Aircraft

In actual combat, fighter pilots have reported marked resistance of bullet-proof panels to heavy cannon fire, such as that from a 20 mm. enemy shell.

Various shapes of windscreen panels are now being made to fit the individual types of frames for fighter aircraft of all kinds and certain bombers. Some of these have an auxiliary " demisting " panel attached, fitted with a hot air circulator and/or a chemical dryer, such as anhydrous copper sulphate or calcium chloride, to absorb all moisture.

Further developments in bullet-proof windscreens have resulted in the production of curved types of simple conic sections made from a plurality of similar or varied thickness sheets curved to a suitable radius, laminated and sealed as for the normal type of flat windscreen.

Advantages of this construction are stated to be a marked increase in aeroplane speed and a better resistance to bullet or cannon fire impact. As a compromise between the ideal curved type of bullet-proof windscreen and the flat, certain makes embody a composite of normal screen set at the usual frame angle with a forward outside slightly curved panel made as a simple sandwich and set at a more acute angle. This is beneficial from considerations, affords slight protection for the screen proper and reduces frost build-up by its ability to respond more rapidly to meteorological changes. It has the disadvantages of increasing the weight and necessitating additional framing. Curved thin laminated glass panels are favoured by certain American aircraft builders in view of the increased speed attained.

Air-Blown Perspex Shapes for Aircraft

Hemispherical domes for sextant observations (" Astra " Domes) are moulded from a special blemish-free quality Perspex to comply with Air Ministry Specification No. G.514.

The process is usually carried out on a circular base plate with a centre hole through which low-pressure air is blown against a sheet of hot plastic Perspex until the desired dimension is attained.

The fitting of these domes to high-speed aircraft gives protection from the airstream to observers (navigators) taking sextant observations and a sextant fitting is attached to all domes.

The optical properties of the dome must be uniform and conform to certain rigid requirements since they are primarily used for accurate position plotting by the

navigator (observer). They must also be sufficiently robust to withstand the usual handling without strain or distortion and exhibit a very high finish.

To avoid likely local strains that may develop on installation the edges of the dome are turned to form a flat flange. In addition to stringent visual examination, each dome is subjected to a quantitative optical test by means of which the exact mean deviation of a standard beam of light at each 10° interval of altitude between 10° and 80° is observed and the total variation of deviation with azimuth at the altitudes specified converted into true readings for any particular altitude.

The corrected altitude readings lying between 0° and 80° are entered boldly in the appropriate spaces on a refraction card which is attached to the inner side of the dome. (An example of such a card is given herewith.) The manner of carrying out the test is given in an appendix to the specification quoted.

Pear-shaped and similar observer " fairings " are also produced by controlled air pressure blowing. There the final shape is arrived at by using a sectional base plate of design appropriate to the plan projection of a horizontal cross-section of the fairing and blowing as for the " Astra " dome. The same principle is now being applied to the manufacture of hoods and cabins of compound structures where differential pressure blowing controls the sectional shapes.

Among the miscellaneous moulded Perspex shapes for aircraft parts may be mentioned camera windows, cabin panels, side panels and cover plates made by simple moulding or air blowing.

Advantages of air blowing over the recognised methods of moulding (except where desired shape is not readily attained by blowing) are the ease of manipulation, dispensing with moulds, finer finishes obtainable, freedom from distortion, even strain distribution and uniformity.

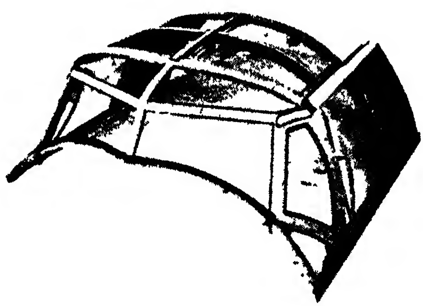


Fig. 324.—Beaufighter Hooding, by Weathershields, Ltd.

For very large parts of compound shape resource is often had to welding of sections independently moulded or blown, and marked advances in plastic welding technique have recently been made. The welding compounds used are mostly secret, but the basis is a suspension of polymer in monomer suitably plasticised and diluted to the desired consistency by solvents. After welding, heat treatment is applied and the weld area is buffed down until the requisite finish is obtained. A skilfully manufactured welded construction can hardly be distinguished from one made as a complete unit.

Standardised Cabin Windows for Aircraft

To meet the growing need for a standardised type of cabin window for aircraft, embodying the special features of design and construction called for by different manufacturers, the British Tyre and Rubber Company has developed a product which has been warmly welcomed by leading constructors and will undoubtedly make a valuable contribution towards simplification and acceleration of output.

Mounted windows have been designed to meet a wide range of requirements and the following outstanding points are stressed :—

(1) Flexible (rubber) mounting, to accommodate the expansion and contraction of the transparent material.

(2) Window portion capable of being easily pushed out in emergency and easily replaceable if damaged.

(3) Watertight junction between window and rubber mounting.

(4) Flush exterior surface, maintaining the lines of the fuselage and eliminating drag.

(5) Can be contoured to match shape of fuselage if necessary.

(6) Metal frame ensures easy installation by riveting to stressed skin or plywood base.

Circular windows of 9 inch and 12 inch diameter are in production; and any reasonable size or shape can be made to order.

The Bristol Bombay Troop Carrier is fitted with B.T.R. windows.

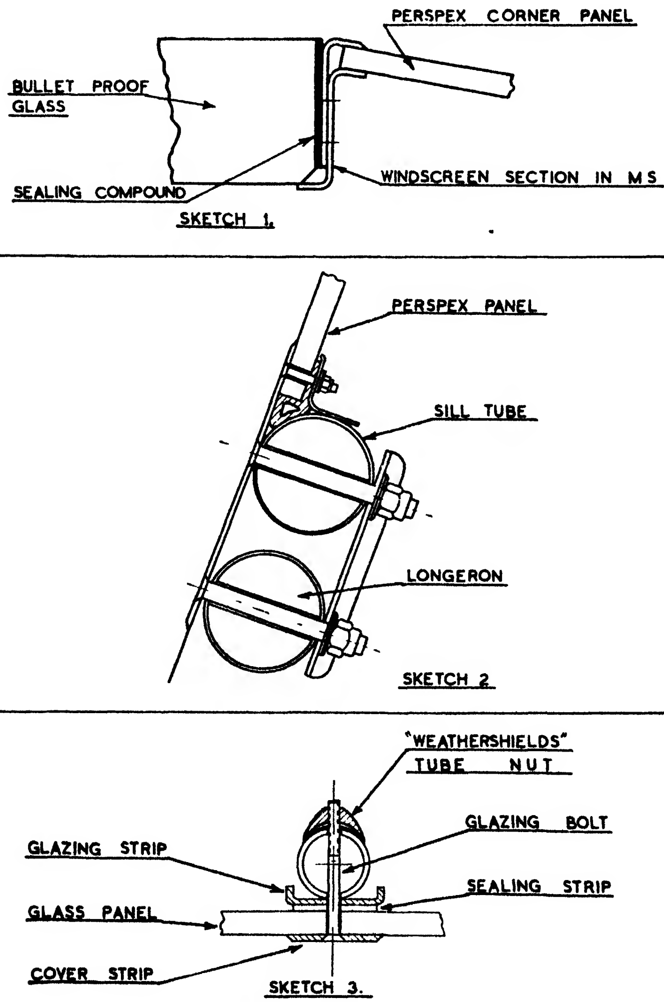


Fig. 325.—Installation of transparent enclosures.

Beaufighter Windscreen and Hooding

Pilots' windscreens, sliding hoodings and completely glazed windscreens and hoodings are manufactured by Weathershields, Ltd., of Birmingham, who specialise in this class of aircraft components. Among the types manufactured are the Wellington and Beaufighter assemblies, totally different in construction; both are proved to be efficient contributions toward present-day large-scale airframe production.

A point worthy of note is that these assemblies are designed as complete fitments ready for installing on the aircraft, the designers having placed all detail work in the sub-contractors' hands, thus saving considerable man-hours on their production lines. Such items as spotlight brackets, lanyard brackets and mounting brackets for equipment, are now considered sub-contractors' supply, all leading towards the avoidance of bottle necks in the main contractors' plant.

The Bristol Beaufighter windscreen and hooding, is an ideal example of progressive planning, an interesting feature in the design being the remarkable good visibility for the pilot. The forward view calls particularly for comment, owing to the unusual formation of the windscreen pillars, which total $\frac{7}{8}$ inch in width. This design could be used to advantage on the other fighter aircraft.

The tubular steel and pressed section main frame as a welded structure makes a perfect glazing fixture; and the method of attachment of the completed assembly to the sill tubes and formers of the fuselage is as shown in Fig. 325. The extensions of glazing strips are secured to the fuselage through the sill tubes. These glazing and jointing strips are approximately three inches wide in 20*g* alclad, and through careful jigging fit snugly on the stressed skin of fuselage. Bolting up on this principle is an easy operation, and total fitting time is cut to a minimum.

It will be noted that the jointing strips are bolted through the longeron tubes, using swaged bolts and nipple nuts, spaced approximately three inches apart; and standard A.G.S. screws, bolts and nuts are used for fixing the rear former and the front screen section. Special bolts are therefore avoided, which is an ideal move towards standardisation and subsequent saving in machining costs.

Weathershields have recently perfected a new type of nut for incorporation on windscreen and hooding assemblies, especially in regards to final fitting to the aircraft; these are known as tube nuts. The nut can be hot stamped or pressed and is self-locking on the tube. To avoid the knobbling or riveting over of the screw after fitting, the slotted type has been devised, which grips both the screw thread and the tube. It has been proved beyond doubt that the riveting over of the screw is bad practice, the hammer having the undesired effect of loosening the hold of the screw permanently. This nut also avoids the countersinking of the tube, which has a marked weakening effect always.

The Wellington windscreen and hooding, one of the lightest constructions of to-day, is made almost entirely of light alloys, full use being made of M.G.7 Sections. This weldable alloy is well known, and in the Wellington windscreen its incorporation has left little to be desired.

Owing to the geodetic framing of this machine and the fabric skin, great care has been taken on the jointing of the windscreen unit to the main framing. The finished windscreen and hooding assembly is bolted in position before the skin is fitted, the cover strips on the hooding being used for fixing the fabric. Clean jointing is thus carried out effectively.

DE-ICERS

The formation of ice in flight is a hazard of the most malicious type; one which arises unexpectedly, which cannot be plotted on a chart nor accurately forecast to the pilot, even by the remarkably efficient system of weather-reporting developed during the last fifteen years.

Ice formations are treacherous. They build up quickly; there are no strict definite altitudes at which they take place. The pilot has no safe assurance that they will not occur in the upper air even when ground temperatures would seem to make this impossible.

The danger of ice formation is not only the actual weight of the ice that accumulates on the plane, but in the deformation of the contour of wings, stabilisers, fin and propeller, which seriously affects lift and controllability.

Chemists and technicians considered, therefore, that reliable mechanism for the prompt removal of ice from these parts, at the pilot's will, no matter when it begins to form, offered the surest means of overcoming the danger.

Nature and Operation of De-Icers

The British Tyre and Rubber Company's De-Icer consists essentially of a rubber overshoe, attached to the leading edge of each of the aerofoils of the aircraft and containing tubes capable of inflation by means of air pressure. The surface of the overshoe is formed of a thin sheet of vulcanised rubber which has been treated, during manufacture, with a certain special mixture of oils. Thus the rubber, which in itself possesses a low adhesion tension toward water, is permanently lubricated by the oils and is, therefore, still less liable to collect moisture.

Exhaustive tests have been made to determine the effect of de-icers on the aerodynamics of the aircraft to which they have been fitted, and these tests have shown that there is no appreciable change in performance.

The following particulars of a typical installation of de-icers will make clear what apparatus is necessary, but it must be remembered that every installation must be treated as a special undertaking, and modifications in the number and disposition of inflatable tubes, periodicity of inflation, etc., may be recommended should B.T.R. engineers consider this advisable. Further modifications may be rendered necessary by the presence of landing lights, gun positions, etc., in the leading edges of the wings, etc.

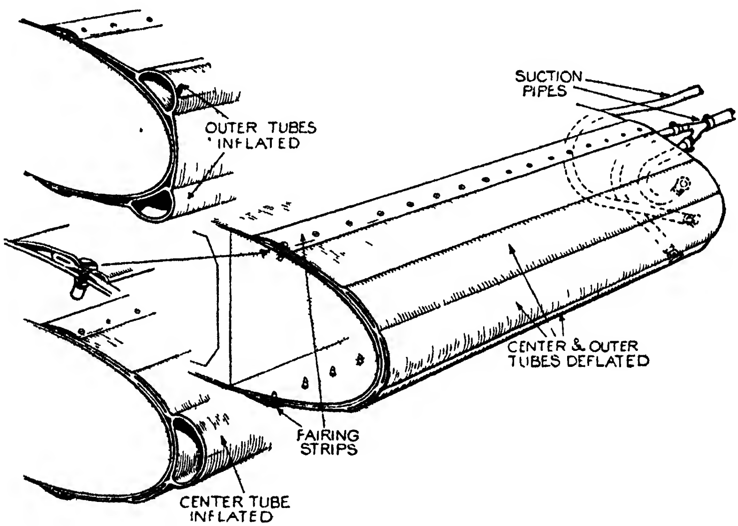


Fig. 326.—The B.T.R. de-icer is a pulsating rubber overshoe attached to the wing, tail unit and radio mast.

Wing Surfaces

The mechanical means of removing ice, excluding the mechanical equipment used in its operation, consists of three major parts. They are :—

(*a*) The inflatable tube sections positioned along the leading edge of the aerofoil.
(*b*) Elastic sections of reinforced rubber on either side of the tube section.
(*c*) Fabric-covered steel reinforcing strips used for attaching the assembly at its outer edges.

The inflatable member is usually composed of three longitudinal tubes built into the main body of the de-icer, inserted during construction between the plies of rubber. The tubes are of rubber and fabric, which gives them a limited stretch. When installed on an aeroplane the middle tube is centred on the leading edge, with the two outer tubes above and below it respectively. These tubes are inflated by compressed air, the centre one being inflated by itself alternately with the outer ones, which are inflated together. The inflating and deflating of alternate tube groups give a rocking action which cracks the ice and lifts it so that the air stream can get beneath it and sweep it clear of the machine.

When deflated the tubes collapse and lie flat, each being about 3 inches wide at the inboard, and tapering to 1¾ inches at the outboard end. The tubes are usually back-connected through to the inside of the wing, aluminium tubing connecting them to the air supply. The elastic sections are all-rubber portions, which are given a 30% elongation when installed, and by their elasticity allow the tubes to expand and rise when inflated.

Control Surfaces

De-icers for the control surfaces and radio mast are made on the same general principles as those for the wings, except that, being mounted over a smaller aerofoil, only two tubes are used instead of three. A variation of this type, built for stabilisers and surfacers having a sharp leading edge, has the seam between the tubes following a sine curve, rather than a straight line down the leading edge. When inflated, this type gives a scalloped effect, leaving practically no dead areas to which ice can cling.

Control of B.T.R. De-Icers

Controls for the operation of the mechanical part of the de-icer equipment are located in the cockpit, conveniently placed so that the pilot can start or stop the de-icer as needed. Thus, when going into an ice-bearing mist, or upon learning that

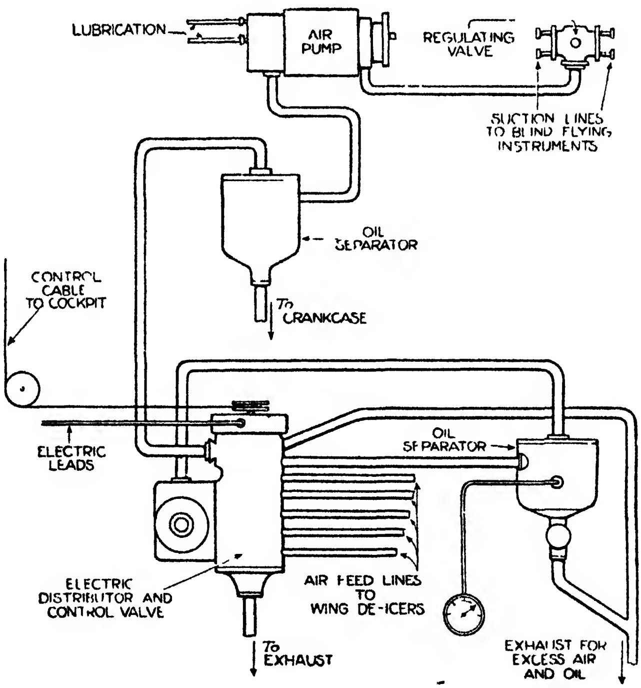


Fig. 327.—Layout of B.T.R. de-icer on Whitley.

ice has started to form, he need only set the control and the pulsating action on the leading edges starts and continues automatically. When he is safely out of the ice area the equipment can be turned off.

A single pump provides the necessary air pressure to inflate the de-icer tubes on all single-engined aircraft. The intake side of the same pump supplies adequate suction to operate a complete set of the commonly-used navigation instruments such as turn

and bank indicator, directional gyro and artificial horizon, and eliminates the need of venturi tubes, which are ordinarily put out of operation by relatively slight ice formations.

Multi-engined planes are generally equipped with two pumps.

In the air pressure line from the pump it is necessary to install an oil separator. In addition to removing the oil vapour from the exhaust of the pump, it serves to regulate the pressure of the de-icer tubes by means of an integral relief valve. A second oil separator is now frequently recommended because the circulation of oil under pressure through the pump may result in an excessive volume of oil finding its way into the air feed lines. The second separator merely separates the fine oil vapour from the distributor to the actual de-icer tubes.

From the oil separator the air pressure is passed to a distributing valve which, as it rotates, controls the inflation and deflation of the de-icer air tubes. Several types of valves are available for use in different types of installations.

Standard distributors are made with 2, 5 and 9 ports for aeroplanes of various sizes. Whether driven electrically or by the tachometer shaft, the entire cycle of inflations is usually completed in approximately 40 seconds.

Protection of Propellers

The B.T.R. syatem of protecting the propeller is based on the feeding of a de-icing solution over the surfaces of the propeller blades. The equipment used for obtaining this result consists essentially of a slinger ring mounted on the back of the propeller hub and a means of supplying the de-icing solution to the slinger. A Rotol de-icing installation is illustrated and described on page 343.

The method of mounting to the hub must be modified to suit various propeller installations. The essential part is the location of the tubes spilling the solution upon the blades. These tubes are so placed that they run along the blades parallel to their centre lines and from points just below the respective leading edges, when the blades are in cruising-pitch position.

The de-icing solution is fed into the slinger ring through a tube mounted on the front of the motor case leading into the slinger. This tube is connected to a supply tank which, in many cases, can be so located that gravity alone will operate the feed. In other installations, air pressure from the exhaust side of the instrument pumps, together with a suitable relief valve, may be used. In still other cases it may be necessary to use a small electric pump to feed the solution to the slinger.

A three-blade propeller should be supplied at the rate of approximately two quarts per hour, and on this basis a three-gallon tank of the solution was used for a two-motor plane on test, giving a supply adequate for three hours' use of the propeller de-icing equipment. A control valve to regulate the flow of the solution to the suggested rate is included in the installation.

It should be noted that every system of propeller de-icing should include a spinner over the front of the propeller hub. This is covered with a special rubber, which is kept saturated with B.T.R. de-icer oils to minimise the adhesion between the ice and the spinner, and to permit the ice to be thrown off by centrifugal force in small particles, while balance and general efficiency remain unaffected.

B.T.R. Abrasion Shoes

The B.T.R. abrasion shoe is a light-weight rubber covering for surfaces not equipped with de-icers, and is designed to resist the abrasive action of rain, sleet, snow, wind, sand and pebbles.

While the machine is on the ground, loose material of this kind is often thrown back against the tail in the blast from the propeller. Serious damage may be suffered by the tail surfaces, especially when the air stream strikes injured edges. Pebble holes ¼ inch to ½ inch deep, for example, have been found on the leading edges of the control surfaces. The soft rubber of the abrasion shoe absorbs the force of even the largest pebbles, causing them to bounce off without injuring the edges.

The abrasion shoe consists of a moulded rubber "V" section nose-piece, which is applied to the leading edges and supplemented with a thin flat fabric of reinforced sheeted rubber extending underneath, as far as the protection is needed.

The moulded rubber "V" nose-piece weighs approximately .17 lb. per foot, and the flat, thin, reinforced sheeted rubber weighs approximately .24 lb. per foot, for a normal width of 12 inches wide.

FIRE-FIGHTING EQUIPMENT IN AIRCRAFT

By A. MATHISEN, B.Sc.

TECHNICAL DIRECTOR, GRAVINER MANUFACTURING CO. LTD.

The Elimination of Fire

THE outbreak of fire, whether in the air (fortunately in peace-time a rare occurrence) or on the ground in a crash, has always been one of the principal perils of flying, and many efforts have been made to eliminate the dangers resulting from it.

For the ideal fire-extinguishing equipment there is a number of desiderata. The causes of fire on the ground in a crash may be one of two. It may result either from the fracture of a pipe or a tank and the flooding of hot engine parts with liquid fuel or vapour, or from a similar flooding when the machine turns over on its back. In either case it may not be possible, for one reason or another, for the pilot to actuate the extinguishing apparatus himself, and it is therefore desirable that it should automatically come into operation when required. In addition to the pilot's control, it is, consequently, desirable that there should be two other forms of control. The one can conveniently be made to work by the force of gravity; so that when the attitude of the aeroplane is seriously altered or becomes completely reversed, a plunger, or some similar contrivance, is automatically released and sets the appliance in action. The other, to operate in a " crash " proper, clearly may be made to depend on inertia and so designed that when the rate of deceleration exceeds a certain figure of *g* it also makes contact.

In addition to these automatic devices to cover ground risks, it is desirable to guard against the danger of fire breaking out in the air. Here it is not necessary, as in the other two cases, to examine the cause but only to go into the effects, and therefore a flame or temperature-operated switch, on the lines of those already familiar for the protection of buildings, is what is needed.

Once they are set down, the requirements appear obvious and the methods of fulfilling them not beyond human ingenuity. It is none the less only recently that success has been met with in incorporating all of them in one apparatus. Anything that will lessen the danger of fire and increase the confidence of pilots and the public in the safety of flying is of general interest and importance. It is in its way as important a step as was the adoption of the parachute—and very similar in its significance.

In war, it should have equally important effects in increasing the morale of pilots and reducing the number of casualties. The fact that the setting of an aeroplane on fire in wartime does not necessarily mean the loss of machine and pilot, as has hitherto been the case, is a point of very considerable moment, and will undoubtedly have important repercussions, not only on pilots, but on those responsible for the conduct of air warfare and the provision of personnel and material. The provision of equipment of this character will undoubtedly become a regular feature of all aeroplanes—civil and military.

Fire Prevention Committee

The problem of preventing and extinguishing fires upon aircraft has for many years received the attention of Government Departments and aviators and, as the Aeronautical Research Committee Reports and Memoranda Nos. 691, 795 and 796 officially published by the Air Ministry show, the British Air Ministry shortly after the Great War appointed a Fire Prevention Committee upon the suggestion of which experiments were carried out at the Royal Aircraft Establishment, Farnborough, with a view to discovering the principal causes of fire in aircraft, and with a view to developing means for combating the fire peril.

The Fire Prevention Committee came to the conclusion that the risk of fire in aircraft crashes was the most serious problem, whereas, on the other hand, risk of fire in the air was comparatively small and a non-automatic apparatus developed for preventing such fires was not adopted, partly on account of its limited utility, but principally on account of the weight of the apparatus.

Causes of Fire in Aircraft Crashes

The Fire Prevention Committee ascertained that in a very severe crash inertia forces burst the fuel tanks and fracture the pipes which extend from the tanks to the engine compartment, and oil and fuel are bound to escape in considerable quantities and in-

flammable vapours will be generated rapidly if fuel or oil makes contact with hot metal parts. If then from any cause these vapours be ignited a sheet of flame envelops the aircraft from which escape or rescue is almost impossible.

Ignition of fuel or oil may be caused by numerous agencies, but the most serious source of ignition in a crash is flame caused by hot exhaust manifolds or exhaust pipes coming into contact with petrol or oil splashed metal surfaces such as the interior of the cowling. Moreover, in a crash when the engine hits the ground grass, twigs and other combustible substances may burst into flame which instantly ignites vapours created by petrol or oil which may have cascaded over the engine or be flowing on to the ground where the wreckage is lying.

Use of Methyl Bromide

The Air Ministry specify that fire extinguishers for aircraft shall contain methyl bromide, the most effective fire-extinguishing medium known to science. Methyl bromide is liquid only when under pressure and evaporates with intense lowering of temperature when liberated from a pressure container. The action of this substance on an aero-engine is two-fold :

When squirted in the form of fine jets on to hot metal parts an intense lowering of temperature takes place, and if, therefore, in a crash a sufficiently large quantity of methyl bromide could be sprayed upon an aero-engine, the temperature of hot parts would be lowered below ignition temperature of inflammable substance and by this means ignition of petrol and oil vapours could be prevented.

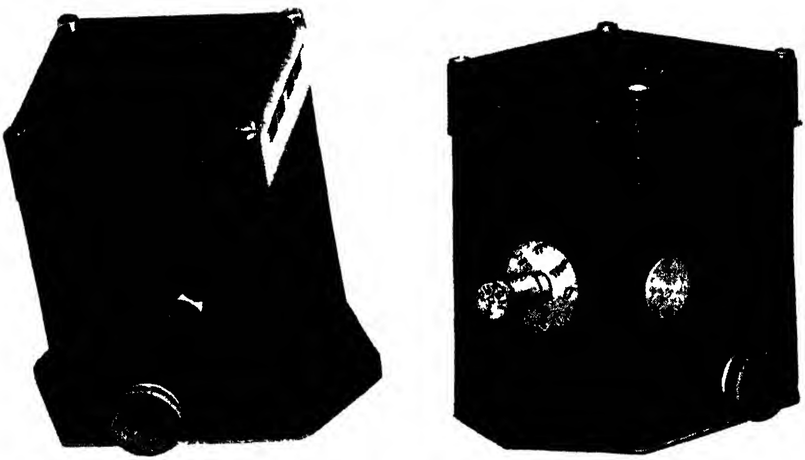


Fig. 328.—*At left, gravity switch; right, inertia or crash-operated switch.*

When considering the use of methyl bromide as a fire extinguishing medium it is important to know that if an ounce of methyl bromide is squirted into a beaker containing 8 to 10 ozs. of burning oil or fuel, black fumes are evolved and the fire dies out, due to a powerful inhibiting action of the methyl bromide. If, therefore, a sufficient quantity of methyl bromide can be introduced into a fuel flooded engine compartment fire can be prevented, or effectively extinguished if it is already burning.

Functional Requirements

To utilise this liquid as a fire-extinguishing medium upon aircraft to best advantage the Air Ministry have called for an apparatus which functions under the following conditions :

(1) Automatically as the result of a crash involving an impact of not less than $6g$, in which case the extinguisher must discharge its contents in the engine compartment in a short period so as to prevent a fire from starting.

(2) Automatically in the case where an aircraft turns over on its back inadvertently during landing with insufficient impact to ensure operation of the inertia switch (i.e., impact involving deceleration of less than $6\,g$).

(3) Automatically to discharge within five seconds in the event of a fire during flight or on the ground.

(4) When desired by the pilot (i.e., when a crash appears inevitable) by a simple push-button switch in cockpit.

The weight of the apparatus must not exceed 12 lbs. and the apparatus must require very little inspection or maintenance after installation upon an aircraft.

Extinguisher

The most important items of the Graviner Equipment is the extinguisher proper, and this comprises a copper bottle containing 3 pints (6 lbs.) of methyl bromide. The bottle is provided with a novel and patented form of discharge head of extreme simplicity. This head contains a fuse which, when ignited by any type of electric battery, effects opening of the discharge head, permitting the bottle to empty in a few seconds.

Fig. 329.—Graviner extinguisher bottle and bracket.

The bottle is mounted in a bracket in which it is held by an ordinary form of clip and the discharge head engages a junction box device from which distributing pipes extend to the engine compartment.

To utilise to the full the sudden and powerful rush of methyl bromide a novel form of distributing pipe system serves to spray the engine surface as well as the interior of the cowling with methyl bromide, particular care being taken to souse the exhaust manifold and pipe system and other fire danger sources with methyl bromide. In

single-engined aircraft the extinguisher is usually mounted in the pilot's or other personnel's compartment, but on twin or multi-engined aircraft an extinguisher should be mounted in each nacelle or engine compartment.

Crash Switch

To effect discharge of the extinguisher in a crash, Graviner Equipment incorporates a special inertia or crash operated switch which is set to operate at a value of about 5 to 6 *g*. The switch operates instantaneously at the moment of impact to ignite the extinguisher fuse and the speed of operation between impact and commencement of discharge of methyl bromide is comparable only to the speed of operation of a gun from the pulling of the trigger to ejection of the bullet.

The engine is therefore inundated with methyl bromide whilst the oil and fuel tanks may be in the process of fracture and the engine should be cooled far below ignition temperature of inflammable substance by the time fuel or oil vapours can reach the engine and, in this manner, the fire risk in aircraft crashes is very materially reduced.

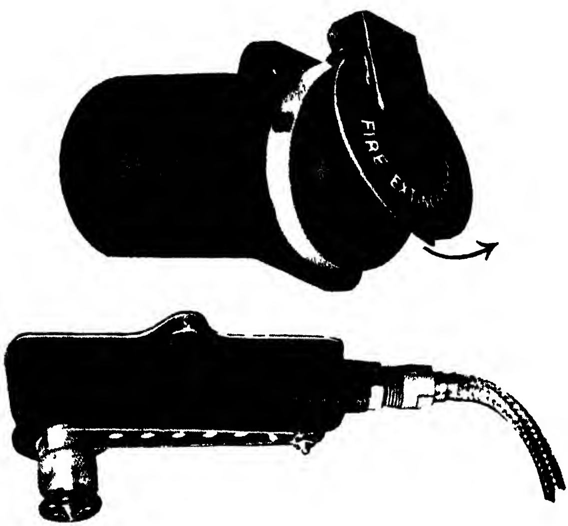


Fig. 330.—Push-button control switch, above ; flame and temperature operated switch, below.

When Aircraft Turns Over

In order to meet an Air Ministry requirement the Graviner Fire Fighting Equipment as originally designed has been modified to ensure automatic discharge of the fire extinguishers in the case where an aircraft inadvertently turns over on its back during landing with insufficient impact to ensure operation of the inertia switch (i.e., impact involving deceleration of less than 6 *g*).

To meet this requirement the gravity operated switch has been added to the equipment and this is not effected by impacts but operates when a machine turns over on its back, and the extinguisher is provided with an internal valve mechanism which ensures discharge in upright or inverted positions.

Fractured Fuel Pipe

Fire may be caused by fractured fuel pipes and when they occur they are, as a rule, disastrous as it is impossible to get away and the fuel-fed flames are fanned into an inferno by the slip stream. The Graviner Equipment therefore comprises a flame responsive switch which operates the extinguisher instantly when flames appear in the engine compartment and the subsequent inundation of the engine and the interior of the cowling may be relied upon to extinguish the fire.

Push Button Control

When crashes appear inevitable it is important to effect discharge of the extinguisher at the earliest possible stage and it is for this reason that the Graviner Equipment incorporates a push-button switch, which when operated by the pilot or other personnel effects discharge of the extinguisher.

The electrical circuit includes the fuse device and the three types of switches any one of which will fire the fuse and cause discharge of the extinguisher. The circuit is usually connected to the ordinary aircraft battery, and any voltage is suitable. No current flows in the circuit under normal circumstances so that no interference is caused to radio circuits. A small current of a fraction of an ampere suffices to fire the fuse and the lightest approved type of aircraft electric circuit wire is suitable.

Bottle and Piping

The extinguisher bottle, which is a solid-drawn copper vessel, containing 6 lbs. of methyl bromide gassed with nitrogen to a pressure of 60 lbs. per sq. inch, is mounted on a special bracket placed behind the fireproof bulkhead in the engine nacelle. The fluid is carried to the engine by a ½ inch flexible pipe, with bulkhead and other fittings of standard Air Ministry design. The fire-extinguishing bottle and bracket are mounted at the back of the fireproof bulkhead.

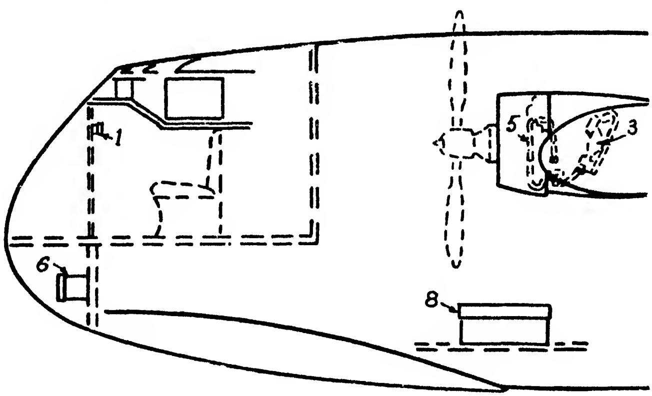


Fig. 331.—*Position of some of the components :* (1) *Push-button switch, one per engine, within reach of pilot ;* (3) *extinguisher bottles in nacelles ;* (5) *terminal block ;* (6) *crash switch, forward and at bottom of fuselage;* (8) *standard aircraft battery.*

The bottle is mounted so as to discharge in the head-downwards position, although when accidentally inverted in an upturned machine the internal sliding valve of the type generally common to fire extinguishers ensures that liquid discharge still takes place. The bottle is so designed that it can be easily withdrawn from the bracket for inspection or replacement. The charged bottle weighs 9 lbs., and it is held in position by the horn-shaped clip over the top and the clamping wire, which can be instantly released by a spring clip. The release of the gassed liquid is effected by an electrically operated fuse and an explosive charge, so arranged that the end stopper in the bottle is blown clear, and arrested by a cross baffle leaving an unrestricted opening for the flow. The arrangement of the plug-in switch is also shown. On some patterns of extinguishing bottle there is an extra outlet nozzle at the side, which is brought into action by the removal of the bottle from the bracket, so that it can be used by the pilot as a hand extinguisher.

The extinguishing fluid passes down an ½ inch flexible pipe to the air intake from the engine in which a spray nozzle is fitted. It then passes to a Y connection spray nozzle by ½ inch diameter 20 S.W.G. piping, and is continued by two perforated pipes of ⅜ inch diameter 20 S.W.G. One of these pipes passes centrally below the engine and returns along the exhaust stubs, while the other encircles the carburetter system,

rising vertically at the end of the engine, and extending along the front of the engine and back along the other side of the blower casing and the air intake. These pipes have blanked-off ends with facilities for cleaning operations and testing.

Radial Installation

In the case of a radial cylinder installation, a $\frac{1}{2}$ inch diameter flexible pipe usually extends from the extinguisher to a single-spray nozzle arranged on the air intake. From the nozzle a $\frac{1}{2}$ inch outside diameter perforated pipe extends first in a horizontal loop around the carburetter system, and then in a vertical loop around the engine accessories; finally terminating in a blanked-off end. In connection with the test of a Bristol "Pegasus" engine at the Royal Aircraft Establishment at Farnborough, it was necessary to find out whether or not corrosion was caused by the injection of methyl bromide into the engine air intake, and its subsequent passage through the engine cylinders and exhaust pipes. For the purpose of this experiment the rear of an engine was enclosed behind the mounting plate by a steel casing, designed to reproduce conditions in the engine nacelle of an aircraft. The extinguisher bottle and bracket were mounted on a wall of the enclosing casing corresponding to a position

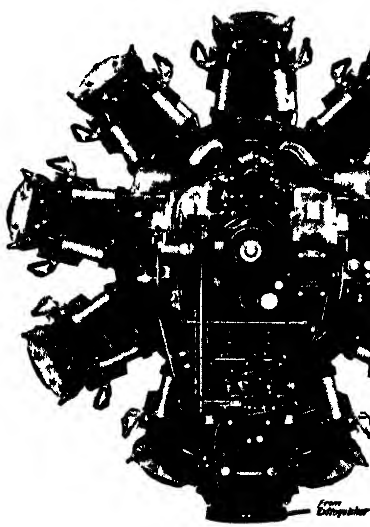


Fig. 332.—Piping layout for Graviner system on radial engine.

on the fireproof bulkhead. A $\frac{1}{2}$ inch outside diameter plain pipe was taken from the extinguisher bottle to a spray nozzle in the air intake. The spray nozzle was of the banjo type, and had a central removable whirling disc and a single $\frac{1}{16}$ inch diameter hole through which a rose type of spray was injected into the air intake. A $\frac{1}{2}$ inch outside diameter perforated pipe extended from the spray nozzle in a practically horizontal loop round the carburetter system, and subsequently the pipe was taken in a practically vertical loop over the engine accessories and blower casing, etc., the pipe finally terminating in a blanked-off and closed end.

Fire Tests

Before the fire tests the engine was started up and allowed to warm up, after which it was stopped while two pints of petrol were thrown over the engine accessories at the rear of the engine. The engine was then started up and a fair quantity of petrol pumped into the air intake, this being ignited by a spark system arranged at the mouth of the air intake casing, resulting in a considerable flare up, not alone in the air intake itself, but also at the rear of the engine. The flames were successfully extinguished as soon as the fire extinguisher was operated by pressing a control switch.

Examination of the engine interior after dismantling showed no signs of corrosion, discolourisation, or other deleterious effects, which is in accordance with expectations, as methyl bromide evaporates when liberated in free air and leaves no trace or deposit. As a result of the tests, the Air Ministry decided to fit air intake nozzles on all installations.

Installation Requirements

Extensive experience has indicated the necessity for installing the various apparatus parts in appropriate positions on aircraft and these can briefly be summarised as follows :

The weight of methyl bromide in each bottle is 6 lbs. and that of the bottle and bracket 4 to 5 lbs. if in copper and somewhat less than half of this if in aluminium alloy. It will therefore be clear that in a crash considerable forces are applied to the bracket and mounting fittings of the extinguisher and it has been found essential to mount the extinguishers on engine supporting aircraft structure members which are likely to remain associated with the engine in a crash, as otherwise discharge of the liquid over the engine cannot be assured. Moreover, the bottle and bracket combination should be mounted so that the supporting bracket points in the the direction of flight. In this case the bottle will be forced on to the bracket in a crash and will not tend to be pulled away from the bracket which may cause the clamping clip or band to fracture, causing the bottle to become detached from the mounting with liability to fracture of the piping, etc.

Automatic Switches

The multi-contact crash-operated inertia switch is designed to operate as many as six extinguishers, and is capable of being set to release at varying values of " *g* " the acceleration due to gravity, a normal value of " 6 *g* " being generally adopted by the Air Ministry. It consists of a small steel pendulum, which on its under face is hollowed out to form a crater, in which a pin mounted at the end of an arm engages. The design is such that the pendulum crater enables the pendulum to remain seated on the pin under conditions of vibration, but any sudden impact corresponding to a deceleration of " 6 *g* " releases the arm, causing the spring-controlled spindle to close the contacts and operate the extinguisher. A small knob on the top of the switch with two positions serves to set the pendulum or to release it for testing purposes.

The inertia switch is mounted in the bottom of the fuselage or hull towards the nose or front, and in actual practice it is found essential to mount the inertia switch on a transverse frame member of the structure of the fuselage or hull close to the bottom. The reason for this is that in a belly landing in which the deceleration applied to the aircraft may not approach 6 *g*, the damage which is bound to be caused to the " skin " on the underside of the fuselage or hull when this is skidding on the ground will result in impacts being applied to this transverse frame member, and this will ensure operation of the inertia switch.

The gravity switch is designed to ensure the automatic discharge of the extinguishers in circumstances where an aircraft inadvertently turns over on its back during landing operations. The switch is operated by a hinged pendulum, which is fitted with a damping device of the toothed sector, pinion, and fly-wheel type. The battery circuit to this particular switch is also supplied over a control switch, such as that for the retractable carriage, the position of which, when down and locked, is indicated by a green light.

The switch therefore remains inoperative until the carriage is down and locked, which covers the conditions associated with inverted flying and aerobatics generally. For convenience with regard to electrical connections the crash switch and the gravity switch are placed in adjacent positions.

Another interesting switch is the flame and temperature operated switch. Again the principle of closing open contacts is maintained, the contacts being held in the open position shown in the drawing by means of a spring-controlled plunger. This is held in position by an upper part comprising a weather-proofed cap with an explosive charge and also a joint which is melted by high temperature. The design adopted is such that in contact with flame or when the surrounding temperature exceeds 140° to 150°C. the switch operates within two seconds. The burning of the charge or the temperature joint allows the plunger to rise and to close the contacts, thereby causing the extinguisher to discharge. These switches are mounted one at the rear of the engine accessories and the other adjacent to the carburetter system. The position of the switches, which are meant to deal with an uncontrollable flare-up, must be chosen so that they are not exposed to minor air intake flash-backs or are too near to hot engine parts, such as exhaust manifolds.

AIRCRAFT JACKING

THE ever-widening scope of the average engineering shop under the changing conditions of war production daily present new problems, all of which bear a relationship to the volume of output. Some of these problems, such as the adaptation of machines to new operations, have a direct and measurable reflection on the total shop output, whilst others, being more or less remote from machine operations, are not so readily connected with the rise or fall in output. In such a class would be included the multitide of lifting operations which become necessary in moving material from place to place. Many of the smaller shops were not originally designed to cope with the concerted war effort now demanded and in consequence are not equipped with the usual systems of overhead cranes, pulleys, hoists, etc. In a market where supplies are short such equipment as is readily forthcoming must be used and often such appliances are found on operations for which they were not originally designed. It is, in consequence, sometimes necessary to " man-handle " large or small machines much more than would have been the case had there been lesiure to plan production along the usual lines.

In this category can be included the lifting, lowering and movement of large sections of the heavier aircraft now widely in production. The lifting of these to facilitate operations beneath the fuselage, testing undercarriage, etc., presented unusual problems and the adaptation of existing appliances to meet the situation. Any such apparatus must possess a number of special features, amongst which the following may be mentioned :—

(1) The lift must be speedy and in as few operations as possible.
(2) When lifted the load may have to be left in the elevated position for an indefinite period.
(3) The apparatus must be capable of transportation easily and quickly to any part of the assembly lines, and there should be an absence of trailing wires, etc., which can cause accidents to those not engaged directly in the operation.
(4) The apparatus must be foolproof and free from minor defects which would interfere with its efficiency.
(5) The units must be solidly constructed to deal with loads which may be " off centre " and must be capable of operation individually in case one or more units should be damaged through enemy action.

The mere requirements as to starting height and lift were sufficient to call for the utmost designing knowledge of experienced engineers who have served a lifetime dealing with such problems. An idea of this can be obtained when it is realised that with modern bomber aircraft the weight to be lifted may be anything up to 20 tons, the starting point 5 feet from ground and the finishing point between 11 and 12 feet. The span of the modern machine makes stability under load a pre-requisite of any lifting apparatus as the slightest " tilting " may result in damage to the machine under construction, a hold-up in the production lines or injury to personnel.

The outcome of investigations resulted in the production of the Duff-Norton aeroplane jack illustrated at the end of this article. The apparatus consists of two distinct lifting jacks assembled in one frame. The upper jack consists of a worm and worm wheel operated by a crank handle on to a ratchet wheel so that the smallest arc described by the crank handle will enable the worm to be operated (the worm wheel, etc., are not shown in the illustration). These worm gears operate a vertical screw inside the lifting ram of the main jack. The operator takes up the load by means of the apparatus in the head of the jack (maximum run out 20 inches) and then takes up the lift on the main, or bottom jack. This comprises the well-known Duff-Norton Governor-Controlled Jack inside a spring-mounted tripod, which is carried on castors. Immediately the load is taken up, the wheels retract and the base of the whole jacking apparatus seats firmly on the ground. In case the surface is uneven the jack may be placed under load at an angle, then during the operation of raising, assumes true vertical position.

The second lift on bottom jacks is taken by moving the operating handle upwards and downwards, after placing the lifting pawl in the lifting position. This section operates a series of gears which transmit the lifting power to the main screw. These gears are held at all points in the lift and " sink back " is impossible. This mechanism is the same as that used in the Duff-Norton Governor-Controlled Jacks which have been used in lifting the heaviest locomotives and bridges over very many years. If the lift

is only required to be taken on the governor-controlled mechanism (lower portion of lifting apparatus) a crank exists to run out ram until the load is contacted. The lifting is then done in the usual way, excepting that there are two speeds—one for lighter loads up to 10 tons and another for heavier loads. When it is desired to lower the load the governor-controlled mechanism is introduced by turning a thumbscrew in the base in an anti-clockwise direction. The extent of this turn controls the speed of lowering, which may be fast or slow at the wish of the operator and the lowering can be stopped at any point by a clockwise turn of the thumbscrew.

Fig. 333.—Duff-Norton governor-controlled aeroplane jack. (Consolidated Pneumatic Tool Co., Ltd.)

HANDLING OF AIRCRAFT

WITH the continued increase in size and weight of modern aircraft, the problem of handling and manœuvering calls for special study. In the early days of smaller and lighter machines it was usually possible to man-handle them into position, especially on the fore-courts, and small tractors adapted from agricultural machines were frequently employed to tow the aircraft to the take-off site. About this time aerodromes were mainly grass and prepared surfaces for runways were little known.

Present-day multi-engined bombers have reached such proportions that it is no longer possible to house them in hangars, so they have to be dispersed around the perimeter of the landing grounds. This means long hauls from the runways and workshops; furthermore, it is essential that runways be cleared in the quickest manner possible to allow for following aircraft to alight. Again, when machines overshoot or miss the runway and encounter soft ground, they must be manœuvered back with care to avoid damage. All this calls for greater power and adhesion than was obtained with the smaller tractor.

Track-laying machines followed the small wheeled type tractors, probably because they were available and, generally speaking, had a greater drawbar pull, but they quickly revealed many shortcomings, not the least of which was the damage done by the tracks to the runways. They were slow in getting from point to point and required a lot of maintenance. It was therefore necessary to design a special-purpose machine. These are now in production, and a specimen is shown in Fig. 334.

The general specification of one such machine includes a four-cylinder petrol engine, developing 38 b.h.p. at 2,200 r.p.m., giving its maximum torque at 1,200 r.p.m., four-

speed close ratio gearbox giving a range of speeds from 2 m.p.h. to 15 m.p.h. at 2,200 r.p.m., and a drawbar pull of over 6,000 lbs. Giant pneumatic tyres are employed, the rear being 12.75 inch by 24 inch and front 9.00 inch by 31 inch. The total weight is 3.3/4 tons, of which approximately 75% is applied to the rear wheels and the balance to the front, which is sufficient to provide good steering control.

A powerful winch forms part of the essential equipment. It is power driven from the engine and is capable of withstanding direct pulls well in excess of 10,000 lbs., and to enable the machine to deliver its maximum rope pull a sprag is anchored to the winch frame. The winch controls are readily accessible from the driving seat as will be observed in the photograph, Fig. 337. Every consideration has been given to robustness in design, accessibility, simplicity and speed in operation, and to reducing maintenance to a minimum.

Fig. 335 shows one of these tractors coupled to the tail wheel of a bomber by a rigid drawbar. This means of towing is used where circumstances permit direct hauls, such as on macadam or concrete runways, forecourts or on grass when conditions are favourable. The rigid drawbar and towing from the stern provide better control of steerage, and are unaffected by the landing wheels passing over potholes, etc., due to the converging linkage and leverage obtained, whereas if the aeroplane were towed forward, undulations of ground would have a marked effect on the steering, unless a long, unwieldy and widely triangulated drawbar were used.

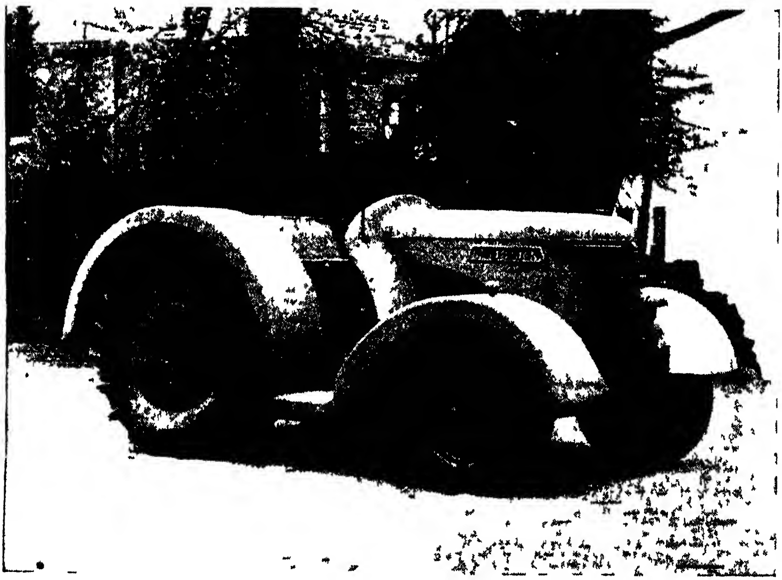


Fig. 334.—David-Brown aircraft tractor, with hydraulic torque convertor.

Another form of towing is carried out by means of the winch rope being coupled to the tail wheel. This method is particularly useful when hauling over grassland or up-grades, and where insufficient traction is obtained to permit direct attachment. In this manner the sprag should be lowered and allowed to trail on the ground. The rope should be above the sprag angle plate and attached to the tail wheel. The tractor is then driven forward until all but the last two turns of the rope have run off the winch drum. The winch is then engaged by de-clutching (with the change speed lever in neutral), accelerating to a reasonable speed and engaging the clutch smoothly. The tractor will at first commence to run backwards until the sprag obtains a firm grip in

the ground and then the aircraft will be drawn towards the tractor with the engine running at full governed speed. When the aeroplane arrives at a reasonable distance from the tractor, it is only necessary to disengage the winch gear, apply slight pressure to the winch drum brake to prevent over-run of drum, and drive tractor to the next stage, or if the ground at that point permits direct towage, apply winch brake hard on and drive forward, remembering that hauling by winch gives about double the pull of the maximum drawbar pull.

It is important that the winch rope should never be run off to its entire length, otherwise the strain may pull out or damage the point of rope attachment. Two laps on the drum will obviate this danger.

Another form of towing not illustrated is by coupling two tractors in tandem. The rear tractor should preferably be attached to the aircraft by a rigid drawbar, as shown in Fig. 335, and the winch rope of the leading tractor should be attached to the front hitch point of rear tractor. There should be a distance of approximately 8 feet between the two machines. This system is much speedier than the preceding method, and is usually resorted to where the number of available tractors permits its use. It calls for some care in achieving synchronous get-away. Having this latter point and the prospect of still larger aircraft in mind, machines similar to those illustrated have recently been developed, incorporating a Turbo-Transmitter in place of the orthodox clutch. This operates in conjunction with the normal gearbox, and provides a smoother start from stationary in getting large aircraft under way. It also allows the engine to deliver its full torque at get-away without skill on the part of the driver, a very desirable feature when the landing wheels of aircraft tend to sink in soft ground, or when steep up-grades are encountered. Another and by no means the lesser advantage is that the hydraulic

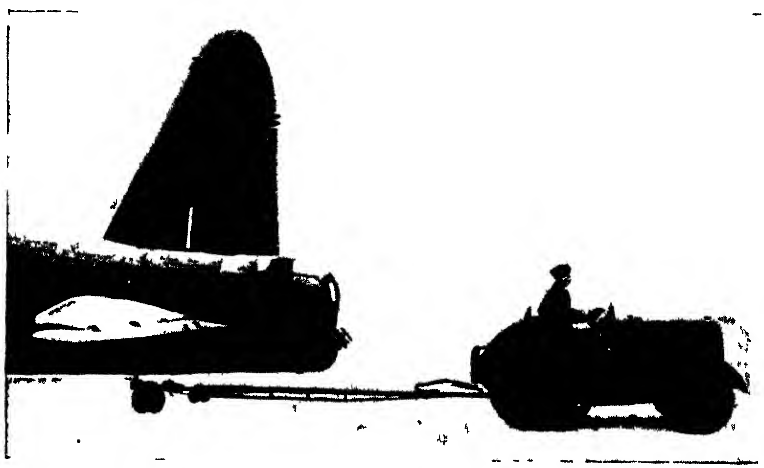


Fig. 335.—Towing a Wellington by rigid drawbar.

torque converter enables tractors to be coupled together and to get away under load from stationary without snatch. It is possible in a measure to disregard the synchronisation of individual engine speeds and torque, making the operation safe and simple, and well within the capabilities of drivers having varying degrees of skill and experience.

Tractors of this type are already in service and will become more generally used as they become available. Summarising this article one might be tempted to express the opinion, "Why not have one large tractor instead of two coupled together?" The answer is that under normal conditions one tractor of the type under review fulfils the needs, two machines only being required under abnormal circumstances. Furthermore, one large tractor would be uneconomical for normal usage and the weight of such a machine would damage the grasslands. Also it should be borne in mind that the

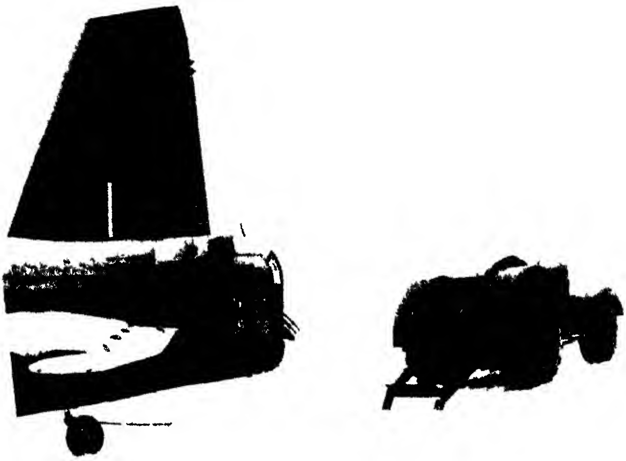


Fig 336 —*Towing by winch, rope, and sprag*

Services have other uses, apart from handling aircraft, for the medium-sized tractors, such as for the towing of bombing-up trailers, petrol tankers, and removal of crashed and immobilised aircraft Tractors are, in fact, an absolute necessity for the efficient handling of aircraft and those ancillary vehicles which are not prime movers

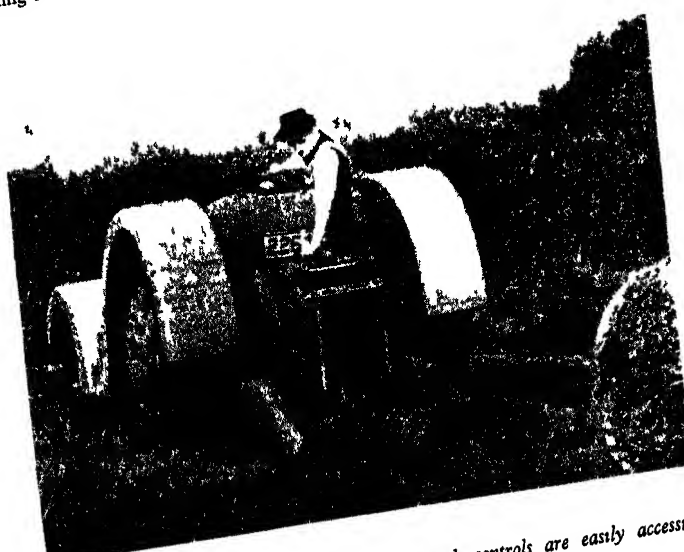


Fig. 337 —*Sprag on David-Brown tractor; winch controls are easily accessible from driving seat.*

THE TECHNIQUE OF DRY SURFACE LUBRICATION

THE high degree of specialisation in aircraft equipment has brought with it problems in lubrication which often lie outside the scope of oil and greases. Thus, high and low temperatures may render standard lubricants inadmissible; plastic bearings and bushes, again, call for a new approach to lubrication. There has been a tendency, perhaps influenced by tradition, to assume that oils and greases are the only lubricants available and must, therefore, be adapted to many problems for which they might be fundamentally unsuited.

Broadly speaking, there are two major classes of lubrication: one in which the lubricant has to carry away heat from working faces, and secondly where heat in any quantity is not involved and cooling does not consequently arise. It is this latter class in which difficulties have arisen, as, for example, the maintenance of low friction in moving parts which may operate only intermittently at low or high temperatures. An investigation has been made of methods whereby dry lubrication can be carried

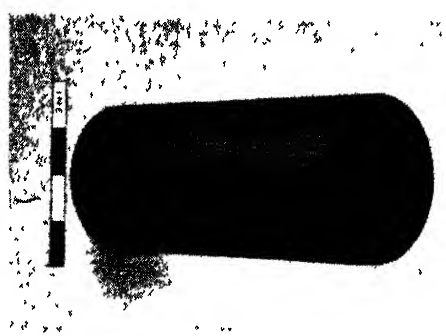


Fig. 338.—Texolex bush; can be dressed with colloidal graphite.

out in the second class of equipment referred to above. A technique which has been developed from these investigations has provided a solution to many problems and can be applied to auxiliary equipment, controls, non-metallic and metallic joints and bushes, toggles and sliding surfaces.

Colloidal graphite dispersed in various volatile liquids is the principle. Such dispersions enable dry slippery films to be formed on any type of metallic or non-metallic surface, which can be air dried rapidly or dried by the application of heat. It has also been found that the method can be applied to engine and auxiliary parts with success where subsequently oil is used for normal lubrication, the film in this case acting as a reinforcement to off-set seizure during initial running-in.

For many years it has been the practice to assemble and run-in engines and to lubricate high-temperature equipment with "dag" colloidal graphite dispersed in mineral oil. Engines and auxiliary equipment, machine tools, reduction gears and moving parts on furnaces and ovens have been lubricated with colloidal graphite, but the new method of employing this product has attacked existing problems from a new angle.

In a pure form graphite is known to be an efficient lubricant. It must, however, be very finely divided so that it can be dispersed readily in light volatile liquids such as acetone, carbon tetrachloride, white spirit and kerosene. That is why colloidal graphite is employed for the purpose, while it has been found that particle fineness is necessary, to ensure the adherence or keying of the dry film to the surface on which it lies. In addition this characterised fineness, enabling as it does the flat particles to lie like tiles, ensures maximum lubricating value from the film.

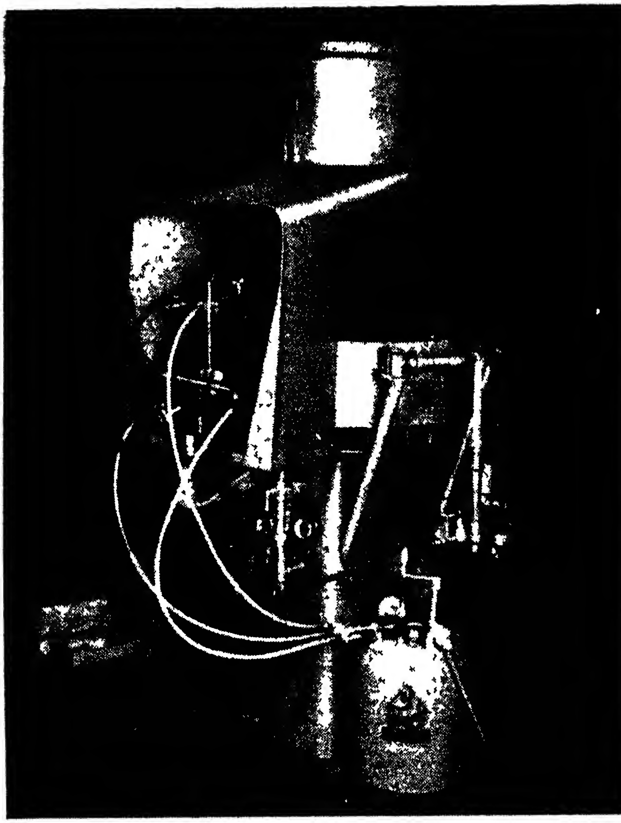


Fig. 339.—Typical spray booth for applying colloidal graphite to small parts.

Static and Sliding Friction

The lubrication of much equipment involves static and kinetic friction. The importance of these two factors may not have been given sufficient attention in the past, particularly where a small starting effort only is available for a mechanism and where static friction must be kept at a minimum. A close examination of the friction characteristics of dry films formed with colloidal graphite made by the Acheson process, in the absence of oil or grease, show the following values :—

	Static Friction	*Kinetic (sliding) Friction*
Steel on Steel with graphite film on both surfaces	0.16	0.06
Steel (Plain) on Steel (Graphited)	0.16	—
Steel (Plain) on Glass (Graphited)	0.14	0.05

It might be stated that the static coefficient of friction, which is a measure of the starting effort required to commence movement between faces, for a film formed with a good quality oil on steel would be in the vicinity of 0.16, while under boundary film conditions the kinetic friction would be 0.04 to 0.08. It will be seen, therefore, that the lubricating effect of a thin film of pure graphite approximates to that for a boundary oilfilm, but the undesirable hydrodynamic effects of the latter, due to

thickening, at low temperatures, are, of course, eliminated by the use of a dry surface which is largely unaffected over a wide range of temperatures.

How Dry Films are Formed

For surfaces which cannot be heated or heat treated in any way, it is usual to employ a dispersion of colloidal graphite in acetone. When this dispersion is applied, either by spray, brush or by dipping, to a piece of equipment, the acetone evaporates rapidly at room temperature to leave a thin lubricating film of graphite. Before the latter is applied, however, the surfaces should be degreased in trichlorethylene or by other suitable methods.

When the film is dry it may be lightly polished with a dry cloth, if desired, and put directly into service. Thus, if a fabric plastic bush is painted with " dag " colloidal graphite in acetone it will be found to dry out in a few seconds and can be fitted into position almost immediately. The life of such a coating or film depends on the work to which the part in question is put. It has an indefinite life, for example, in a blind ended bush where occasionally reciprocation of the pivot or journal is encountered. Where continuous operation is called for provision will of necessity be made for a liquid lubricant feed, in which case dry lubrication would supplement and not be considered alone as a solution of the problem.

By using a dispersion of colloidal graphite in water (" Aquadag ") a thin graphite film can be formed on metallic and non-metallic faces which does not dry out so rapidly. This is an alternative method to the use of colloidal graphite in acetone described above, and may be preferable where the atmosphere is warm and where acetone would be considered too volatile.

A Light Hardening Film

When colloidal graphite, gelatine and potassium dichromate are dispersed in water a solution is produced which forms thin lubricating films that harden under the action of bright light. This technique has been patented in the form of Coating Solution, which is sprayed or brushed on to the face requiring treatment. The latter should be degreased before applying the Coating Solution, and if the piece is warm beforehand the film dries rapidly, hardening at the same time.

Such a film adheres strongly and provides surface protection of bearing faces during their initial operation. It is not easily removed by oil, and, consequently, is particularly suited to work where oil lubrication is necessary, as, for example, engine cylinders. The use of Coating Solution has been more widely adopted in Great Britain, where it was developed, but in the United States other techniques using colloidal graphite are employed, which are referred to below.

Parts which can be Heat Treated

Where a metallic part can be raised to 200° to 250°C. for one to two hours, colloidal graphite dispersed in white spirit has proved most effective. This dispersion can be sprayed on, brushed or applied by means of dipping the parts to be treated in a bath. The graphite film produced is wet and must be baked at 200° to 250°C. for an hour or more when a very dry adherent skin is formed. This technique has proved most suitable where the part in question will be oil lubricated subsequently and where the graphite film is required to off-set incipient seizure, or to facilitate running-in. It has proved valuable on reciprocating surfaces where adequate oil lubrication can only be maintained with difficulty.

Here again, the life of the film depends on local operating conditions. Fig. 339 shows the small spray booth developed by the Process Engineering Corporation of Chicago for the treatment of small parts with a dispersion of colloidal graphite in white spirit or kerosene. The parts to be treated are heated by infra-ray gas heaters, sprayed and dried automatically. From 750 to 1,200 pieces per minute can be treated, the heating period being about twenty seconds at the higher through-put, after which they are sprayed with the colloidal graphite dispersion.

Fabric Plastics

A good example of surface lubrication in this type of material is offered by the " Texolex " bushes, made by the Bushing Co., Ltd., shown in Fig. 338. These have been surface dressed with a dispersion of colloidal graphite in acetone, while the fabric forming the basis for the resin had been previously impregnated with " Aquadag "

colloidal graphite in water. The friction characteristics of such a bearing material clearly indicate its value for self-lubricating bushes and bearings.

It might be added that a graphite film can resist temperatures to over 600°C. That is why colloidal graphite dispersed in kerosene or white spirit is sprayed or dripped on to annealing oven chains, furnace car bogie bearings and the moving parts of similar high-temperature equipment. The heat remaining in the parts to be treated, after they emerge from the oven or furnace, is sufficient to evaporate the white spirit and eave a graphite film, which maintains adequate lubrication. This also eliminates the smoking associated with heavy oils and greases used formerly for such lubrication, a factor of some importance in heat treatment shops employing much equipment.

Research and experiment have been devoted for some years to dry lubrication, and the production methods at present used to treat surfaces for this purpose are the outcome of this earlier work. It is anticipated that as the technique becomes more widely known and appreciated in the aircraft industry, so will there be less unsolved problems. The successful use of thin films formed with colloidal graphite for parting aluminium pipe joint threads, for treating gaskets and for conferring self-lubricating qualities on fabric plastics, points, obviously, to the need for a more widespread appreciation of this technique by production departments.

FACTORY AND STORES EQUIPMENT

FACTORY and Stores Equipment in steel or timber and in a combination of these two, as produced by the Fase Manufacturing Co., Ltd., includes racks for rod, bar and tube storage. These may be arranged for vertical, pigeon-hole or horizontal storage, of standard types, or specially designed to meet customers' requirements. They will accommodate alloy or non-alloy rod, bar and tube of all lengths, sections, and diameters. Tray racks, produced by the same firm consist of a framework of steel channel with angle runners welded on, to hold wooden or steel trays. This method is an excellent one where it is required to store components for pre-selection or kit-marshalling sets, and goes a very long way towards widening the bottleneck of shortages.

Workpans and pan racks have a variety of production or storage purposes. They are made in any size or specification, and can be supplied with or without racks. The racks themselves can be supplied to store a score or a thousand pans.

Tool cabinets will go far towards minimising pilferage, or the mislaying of small tools. These cabinets are made with solid sheet doors, or with doors of wire mesh or expanded metal, and flat key-type locks, or hasps and staples to take customers' own padlocks. The firm also produce small storage bins built up on the "Unit" principle—an excellent method of small parts storage: "Build as you grow." Similarly, extensions to stores may be carried out with either adjustable or non-adjustable shelving either for light weights, or with reinforced shelves to take heavy loads. Rolled steel angle uprights are used throughout.

The Ezyhanger method of clothes storage, consisting of a combination hat and coat hanger made of timber, is hung some 10 feet from the floor when loaded. It has been designed by the Fase Manufacturing Company, Limited, to prevent pilfering, and to obtain the benefit of the upper air for drying purposes.

Some storage racks made by this firm are illustrated in Figs. 11 to 14.

TITLES AND ABSTRACTS FROM THE SCIENTIFIC AND TECHNICAL PRESS

Prepared by R.T.P.3

Directorates of Scientific Research and Technical Development

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R.T.P. Ref.	*Title and Journal*
	PLANNING FROM CONTRACT TO COMPLETION
26229 U.S.A.	*How to Speed Up Production.* (Paper to S.A.E. National Aircraft Meeting.) (P. G. Zimmerman, Canadian Aviation, Vol. 14, No. 1, Jan., 1941, pp. 37-9.)
26271 U.S.A.	*Applying Automotive Methods to Aircraft Production.* (D. R. Berlin and P. F. Rossmann, Aviation, Vol. 40, No. 1, Jan., 1941, pp. 42-3, 122 and 144.)
26383 U.S.A.	*Standardisation in Aircraft Manufacture Discussion at S.A.E. National Aircraft Production Meeting.* (Airc. Prod., Vol. 3, No. 29, March, 1941, pp. 105-8.)
26285 Gt. Britain	*Metal Salvage : Efficient Control and Disposal of Swarf and Scrap.* (D. F. Galloway, Autom. Eng., Vol. 31, No. 407, Feb., 1941, pp. 55-9.)
26385 Gt. Britain	*Swarf Control and Disposal : Equipment for Scrap Recovery.* (D. F Galloway, Airc. Prod., Vol. 3, No. 29, March, 1941, p. 111.)
28854 Gt. Britain	*Routine Production Testing of Aircraft.* (Flight, Vol. 40, No. 1711, 9th Oct., 1941, pp. 232-234.)
29258 U.S.A.	*Aircraft Cost Control.* (G. M. Giannini, Aero. Digest, Vol. 39, No. 2, Aug., 1941, pp. 187-189 and 192.)
29281 U.S.A.	*Factory Expansion (Pratt and Whitney, Curtiss-Wright, Republican, Bell, etc.).* (Aero. Digest, Vol. 38, No. 4, April, 1941, pp. 143-152 and 190.)
29964 U.S.A.	*Warplane Specification Engineering.* (P. A. Beck and R. H. Rubb, Aviation, Vol. 40, No. 10, Oct., 1941, pp. 68-69.)
90 U.S.A.	*Sub-Contracting the North American B-25C Medium Bomber.* (American Aviation, Vol. 5, No. 13, 1st Dec., 1941, p. 32.)

R.T.P. Ref.	*Title and Journal*
	Planning from Contract to Completion—*continued*
1096 Gt. Britain	*Liaison Between Design and Production.* (A. J. Schroeder, Airc. Eng., Vol. 14, No. 156, Feb., 1942, pp. 57-58.)
1343 Gt. Britain	*Mass Production and the Aeroplane.* (Engineer, Vol. 173, No. 4495, 6th March, 1942, pp. 206-207.)
2188 Gt. Britain	*Quality Control (Statistical Method).* (Engineer, Vol. 173, No. 4503, 1st May, 1942, pp. 370, 374-376.)
2258 U.S.A.	*Production Short Cuts (Organisation, Tooling, Fabrication).* (Aero. Digest, Vol. 40, No. 3, March, 1942, pp. 253-301.)
2278 U.S.A.	*Methods of Production Engineering (Part II).* (C. H. Spark, Aero. Digest, Vol. 40, No. 1, Jan., 1942, pp. 292-296.)
2287 Gt. Britain	*Statistical Control of Repetition Work.* (Engineering, Vol. 153, No. 3980, 24th April, 1942, pp. 332-333.)
2432 Gt. Britain	*Organisation of Production.* (Nature, Vol. 149, No. 3784, 9th May, 1942, pp. 507-509.)
2538 U.S.A.	*Production Engineering, Part III (Liaison).* (C. H. Speck, Aero. Digest, Vol. 40, No. 2, Feb., 1942, pp. 188-190 and 198.)
2675 Gt. Britain	*Statistical Control of Production.* (Dr. C. G. Darwin, Nature, Vol. 149 No. 3786, 23rd May, 1942, pp. 573-575.)
3094 Gt. Britain	*The Motor Industry and Aircraft Production.* (H. H. Budds, Airc. Eng., Vol. 14, No. 159, pp. 139-140, May, 1942.)
3561 Gt. Britain	*Increasing Production without Increasing Facilities.* (Memorandum Presented to the Minister of Production.) (Inst. of Prod. Engineers, Vol. 21, No. 6, June, 1942, pp. 204-221.)
3667 Gt. Britain	*Bibliography of Published Information on Production (Organisation, Tooling, Fabrication Methods).* (1941-1942.) (R.T.P.3, Bibliography No. 36.)

29166

STANDARDISATION OF AIRCRAFT ENGINE COMPONENTS

(G. Carvelli, J.S.A.E., Vol. 49, No. 1, July, 1941, pp. 294-300)

Standardisation of engine components should start in the drafting room with use of a system of sample drawings, and dimensioning of parts should be simplified through use of a two-place decimal system.

The importance of standardisation of notes, clearances, tolerances, and other data listed on drawings is emphasised. In addition, threaded parts, gear tooth form, and many such items can and should be standardised, and serious consideration should be given to adoption of the metric system.

Since the Army-Navy (AN) Standards were developed primarily for airplanes and often do not apply to aircraft engines, a new set of standards must be developed for parts used on engines only.

The twenty-odd gauging systems used to-day should be eliminated and only one system used based on a decimal system. The number and letter drill sizes should be replaced by sizes based on a decimal system. It has been estimated by a firm using copper, brass, and aluminium that the saving for this firm alone would be over $1,000,000 a year if a uniform gauge system was used.

The money spent on standardisation will pay dividends beyond imagination, and it is recommended that the management of engine and airplane companies encourage their men to serve on S.A.E committees because, without the managements' support the work cannot be done satisfactorily.

28750

ALTERNATIVE MATERIALS AND DESIGN

(G. F. Titterton, Aero. Digest, Vol. 31, No. 1, July, 1941, pp. 148 and 241)

The author presents a number of suggestions for easing the current situation in the American industry in which the best material for a given job is frequently not available.

Alum. Alloy. Substitution of common alloy for the heat-treated variety requires the use of a heavier gauge and the insertion of alclad washers below the rivet heads. Extruded shapes may be replaced by fabricated sections. Formed shapes invariably entail an increase in bend radius and the consequent change in rivet position (to obtain a flat seat) requires careful consideration. The possibility of obtaining the required extrusion from reworking one in stock must therefore not be lost sight of.

Steels. The difficulty of obtaining standard S.A.E. 2330 Nickel Steel commonly used for aircraft bolts has necessitated the use of chrome molybdenum and modification of the bolt manufacturing equipment, unless the bolts are turned on a lathe. Forgings of S.A.E. 4140 of electric furnace aircraft quality are also difficult to obtain. It is stated that open hearth steels to Government specification can be substituted, provided a proper X-Ray or Magnaflux inspection is carried out. For the early planes of a production order, the use of smith or hand forgings is recommended. The stocks of Cr. Mo. steel (almost exclusively used up to now in aircraft construction) can be conserved by restricting its present use to highly stressed parts and using mild carbon steel (S.A.E. 1020 or 1025) whenever possible.

The alternatives proposed do not necessitate any marked changes in design and for this reason plastics and plywood are not included. When the development of these materials is further advanced, the metal procurement problem should be eased considerably, since complete sub-assemblies of these materials should then become available.

26362

STATISTICAL CONTROL OF MATERIALS AND MANUFACTURED PRODUCTS

(J. Geschelin, Autom. Ind., Vol. 84, No. 3, 1st Feb., 1941, pp. 128-129 and 139-140)

Statistical inspection is essentially a sampling control applied to materials or manufactured articles which are themselves produced under controlled conditions. Once standard conditions have been established, any variation outside some determined limits indicates that some change has taken place which in a large majority of cases can be readily traced.

When introducing the method, it may be safer to restrict it to materials or products which have relatively wide limits of acceptance. As experience is gained, sampling control can eventually be applied to processes in which a 100% inspection was the traditional procedure. As an example, the surface finish of crankpins and journals is given. Originally this required inspection of every crank with the profilometer together with a continuous record of the finishing process so that the latter could be checked and corrected. Eventually the method of finishing would be under control and instead of inspecting every sample, the examination of small batches at hourly or daily intervals will suffice.

The aim throughout is to produce a better article at a less cost and speed up production.

A useful bibliography of twelve recent publications on the subject of statistical control is given.

4749

ON SOME ESSENTIALS IN CONTROL CHART ANALYSIS

(E. G. Olds, Trans. A.S.M.E., Vol. 64, No. 5, June, 1942, pp. 521-27)

In this paper the author indicates the possibility of a new approach to control-chart technique in connection with manufacturing processes. The advantages of quality control of product are widely recognised, and the principles pioneered by Walter A. Shewhart in 1924 have since that time been the object of intensive investigation. Primarily, the present paper is concerned with control with respect to a given standard. By analysing hypothetical examples, illustrated graphically, the basis of the control-chart method is clarified. However, in exemplifying the control-chart technique, the author indicates a method of reversing the usual procedure, by creating uncontrolled

conditions, and then noting whether the tests made locate the "assignable causes" which have been introduced in the experiments. The investigation is carried out with the aid of H. C. Tippett's tables of "Random Sampling Numbers."

2386
PLANNING FOR PRODUCTION IN THE DOUGLAS WORKS

(D. W. Douglas, Aero. Digest, Vol. 40, No. 1, Jan., 1942, pp. 132-133, 250-252)

Planning was begun with thousands of paper models representing machines, jigs and aeroplane assemblies. Department by department, these were placed on huge charts of the plant and arranged in such a manner as to allow materials to stream down the line in the fastest and most efficient manner. Each department was studied individually and as a co-ordinated unit of the whole and its function and equipment analysed in detail, even to the manner and distance an item of material moves from position to position. On the basis of this study, a simplified and efficient routing of production through the departments was drawn up in the form of a flow chart. To meet with this, machinery, tools and jigs were relocated wherever necessary.

Parts from fabricating departments or outside production flow into major assembly departments and emerge as complete sections of wings and fuselages, thus minimising handling, storing and elapsed time. Through timed, straight-line flow the number of handlings of parts and sections has been cut nearly in half. Parts which formerly travelled between floors several times now move during fabrication but a few feet in all. Process and assembly operations now are sped by mechanical means.

Consolidated aircraft has developed an overhead carrier system for setting up four parallel production lines of long-range bombers. The assembly lines for inner wing sections of the Douglas attack bombers are powered with electrical winches, suspended from elevated tracks, the assemblies move past the working position and finally pass directly through the spray booths for painting. A new mobile fuselage assembly line has been introduced which combines the production advantages of the "half shell" construction with the speed of the straight-line assembly. On specially designed steel rails, tubular steel jigs move along, each carrying half a fuselage. With four tracks in parallel, two pairs of fuselage halves are simultaneously in each working position. The assembly is no longer set and removed from the jig, but the jig carrying the growing assembly moves down the line. Upon reaching the final position, the sub-assembly is lifted from the jig and travels on special carriers to a lower floor for interior equipment and final junction of the two halves. The various positions are subdivided into six working areas, each with its own crew performing the same task on each assembly. As each worker has only to perform a single task, the training of comparatively unskilled workers is greatly facilitated.

Mechanised track assemblies for attack bombers and single fighters alone now extend nearly one mile at the Santa Monica plant and have led to reduction of as much as 50% in man-hours required for certain assembly units.

Among the improved types of machinery used in aircraft production, the following are referred to: thread grinders, vertical shapers, hydraulic surface grinders for steel parts, centreless grinder for tubing, tube benders, die sinkers for making metal die from wood models and stretching presses converting sheet metal stock into parts without wrinkling or necessity of heat treatments. Special reference is also made to the Guerin process, making use of rubber pads to act as universal female dies in hydraulic presses. The Guerin process enables the use of semi-skilled workers in sheet metal forming operations formerly requiring high degree of skill and manual precision.

Finally, the great advantage of simplified production illustrations in accelerating output is stressed. These drawings are produced by special artist engineers and (in contradiction to the usual blue prints) are readily understood by the semi-skilled worker.

28747
PROBLEM OF WEIGHT CONTROL

(L. R. Hackney, Aero. Digest, Vol. 31, No. 1, July, 1941, pp. 134-136, 237)

The Society of American Weight Engineers was organised about two years ago with the object of a closer relationship between weight engineers and to correlate weight information. With the co-operation of every major aircraft firm, a Master Weight book has been compiled and the Army and Navy Standard Detail and Group Statements have been revised. The aircraft structure is subdivided into seven main groups. The layout for the estimated weights of the wing group and one of its principal sub-

divisions is illustrated below, the figures applying to a four-engine transport of 40,000 lbs. gross weight.

	Weight	Horizontal Arm	Moment
Wing Group	3964.0	453.5	1798055
Inner Wing Panel	2905.0	450.4	1308602
Outer Wing Panel	642.0	435.4	etc.
Tips	25.0	428.0	
Ailerons	109.0	474.0	
Flaps	283.0	521.0	

	Weight	Horizontal Arm	Moment
Inner Wing Panel	2905.0	450.4	1308602
Front Beam	286.0	416.0	
Intermediate beam		–	
Rear beam	248.0	479.0	
Auxiliary beam .. .		—	
Ribs	536.0	449.0	etc.
Stringers	–	–	
Fittings..	108.0	448.3	
Corrugations	369.0	449.8	
Gussets..	-	-	
Formers		-–	
Channels	—	–	
Stiffeners	115.0	453.5	
Angles	–-	-–	
Fillers	39.0	449.8	
Fabric	---	—	
Metal Covering	668.0	461.0	
Paint	32.0	449.0	
Inspection doors	13.0	474.0	
Fairing	18.0	434.0	
Leading Edge	123.0	406.0	
Hinge and Pins	-—	-–	

Weight control may be divided into : --

(1) Parts entirely within the Design groups control (wing, fuselage, tail etc.).

(2) Parts partly controlled, (fuel system, hydraulic and electrical equipment, armament provisions, etc.).

(3) Parts beyond immediate control (engines and purchased equipment, etc.).

Division (1) amount to between 35% and 50% of the weight empty, (2) 10–15% and (3) 45–50%. It thus appears that roughly half the estimated empty weight of the aircraft is subject to control of the Weight Section. The saving of 1 lb. weight in an aircraft represents a saving of about $10 in manufacturing cost and is worth about $100 a year in pay load to the transport company. A 10% increase in gross weight means a 25% increase in power to reproduce the standard take-off, and a 13% increase in power to obtain the standard rate of climb.

Weight control is thus of the utmost importance. The stress department must be made "weight conscious" and allowance for "unknowns" must be done away with. Progress would be more rapid if detailed weight schedules of all successful models could become generally available.

27609

AMERICAN SOCIETY OF AERONAUTICAL WEIGHT ENGINEERS

(Inter Avia. No. 761, 24th April, 1941, p. 15)

The Society of Aeronautical Weight Engineers has been formed for the purpose of standardising the weight indications of aircraft and simplifying the weight checking of production aeroplanes required by the delivery committees. In order to simplify the delivery formalities, it was agreed to eliminate weighing of airplanes in the gross weight condition, except on the first machine of a contract. Formerly the Army and Navy required that the 1st, 5th, 10th, 20th and each succeeding 20th airplane of a contract be weighed in the gross weight condition. A reduction in weight empty weighings was also agreed upon; now only the 1st, 10th, 25th and one out of each

succeeding 100, as well as the last aeroplane of a contract, are required to be weighed in the weight empty condition. Besides similar simplifications in the weighing of nose-wheel aircraft and flying boats, the Society reached an agreement for free interchange of weight data for estimating purposes.

29257

WEIGHT REDUCTION IN AIRCRAFT DESIGN

(E. E. ROBERTS, Aero. Digest, Vol. 39, No. 2, August, 1941, pp. 146-150, 232-233)

As recently as ten years ago, the existence of the separate weight department as such was relatively unknown in aircraft plants. Necessary weight and balance calculation were made by personnel who could find the time to do them. Only within the last five years has the weight engineer raised his function from that of estimating, calculating and recording to one of actual control. The methods by means of which this has been achieved are described by the author with special reference to the Lockheed firm. Success can only be achieved if there exists the closest co-operation between the aero-dynamic, design and production departments. It is interesting to note that of the total (empty) weight of an aircraft, only about 50% covering the main structural parts (such as wings, fuselage, ect.) is controlled by the firm. The remainder represents purchased equipment (power plant, etc.) or parts supplied by the Government (armament, etc.)

Excluding such items as ducts, fairings, pipe line and electric wiring, seats, flooring, etc., less than 30% of the empty weight remain in the form of stressed material under full control of the aircraft firm. It is evident that further progress is only possible if the firm or government departments supplying the non-structural equipment are rendered as " weight conscious " as those responsible for complete aircraft.

28748

WEIGHT ECONOMY

(J. E. AYERS, Aero. Digest, Vol. 31, No. 1, July, 1941, pp. 138-142, 238)

The article is intended for new draughtsmen in the Aircraft Industry, and he is urged, before the release of any drawings, to consider the following points, amongst others :—

Possible substitution of Al. Alloy for steel
" " " Mg. " for Al. Alloy
" " " Micarta for light alloys
" " " Moulded plastic
Can the part be simplified ?
" " " " spot-welded ?
Can lightening holes be provided ?
Relative advantages of formed and extruded sections and forgings.

Each of the above points is discussed in some detail with examples taken from current aircraft designs. It is interesting to note that due to wear of dies, extruded sections have generally about ten times the tolerance of rolled sheet and this is an argument in favour of formed sections. It is stated that in a recent 6,000 lbs. gross weight aircraft, the weight penalty due to oversize of the extruded stringers (bulb sections) amounted to nearly 9 lbs.

28355

DESIGN AND PRODUCTION PROCEDURE FOR PROTOTYPE AIRCRAFT

(N. N. POLIKARPOV, Aeronautical Engineering, U.S.S.R., Vol. 15, No. 5-6, May-June, 1941, pp. 1-8)

The author examines the methods and procedure for the design and development of experimental (properly-speaking Prototype) aircraft. The need for these is apparent from the tremendous scale of modern aerial warfare and the consequent imperative necessity of utilising materials and technical resources to the very best advantage. The modern military aircraft is becoming an increasingly complicated machine comparable almost to a warship, and this, together with the large-scale production required, imposes the most stringent conditions on the designer.

Two methods of development are available—the design and construction of experimental machines and prototypes for series production as an ancillary activity of large construction plants ; and the establishment of special " experimental " or " prototype " plants. Both have their advantages—the latter appears more efficient under conditions of high-pressure wartime production.

A full scheme of design and development, up to the stage of the "prototype series" capable of actual, operational testing, consists of the following steps :—

(1) Examination of the problem and determination of the fundamental characteristics of the new design. Specialisation and concentration on individual characteristics (speed, etc.) should be avoided; the military aircraft should be an "all-round" machine as far as possible. Scope for modification and "modernisation" is essential.

(2) Setting up the preliminary design (sketch plan).

(3) Construction of the mock-up.

(4) Preparation of the constructional drawings. For mass production, this requires to be very carefully done.

(5) Construction of the prototype series, followed by strength tests, under both static and dynamic loads, vibration tests, etc.

(6) Flight tests, preliminary and operational.

(7) The type is passed into massed production.

Some design points to be watched :—

Durability of materials.
Rapid readiness for service.
Critical analysis of earlier designs which have failed in practice (stability).
Take-off speed as well as landing speed, length of run in both cases.
Production methods and economy of materials.

26328

IDENTIFICATION OF LIGHT SCRAP

(Engineer, Vol. 171, No. 4442, 28th Feb., 1941, p. 145)

Three solutions are recommended as sufficient to identify the light metal alloys when in scrap form: No. 1, 30% nitric acid solution in water; No. 2, 20% caustic soda solution, and No. 3, 5% hydrochloric acid solution in water. Solution No. 1 produces a positive reaction only with magnesium base alloys of the Elektron type. A drop of this solution placed on a perfectly clean surface of such alloy will produce a pronounced white colouration after a few minutes. This test is quite suitable for identification of magnesium base alloy scrap. The alloys aluminium-silicon and aluminium-magnesium-silicon are indicated by a greyish-brown colouration with No. 2 solution. Pure aluminium is indicated when no etching reaction is obtained with Nos. 1 and 3 solutions. If a drop of No. 2 solution produces a black stain, the alloys containing copper (aluminium-copper and aluminium-copper-zinc) are indicated. If on wiping off the remaining caustic soda solution a drop of No. 3 solution removes the black stain, the scrap tested belongs to the group aluminium-copper-zinc.

R.T.P. Ref.	*Title and Journal*
	PRODUCTION USES OF FACTORY LABORATORIES
27648 U.S.A.	*Bell Aircraft Material Testing Laboratory.* (Canadian Aviation, Vol. 14, No. 5, May, 1941, pp. 50-51.)
821 U.S.A.	*Douglas "Cold Room" Laboratory.* (Aviation, Vol. 40, No. 12, Dec., 1941, p. 155.)

2540

AIRCRAFT INDUSTRIAL RESEARCH

(M. Nellas, Aero. Digest, Vol. 40, No. 2, Feb., 1942, pp. 201-206, 221-222.)

Contrary to all popular concepts, research to-day is usually defined as the process of obtaining facts, or the process of obtaining data. Usually it is confined to data that are difficult to obtain and therefore require a special technique and skill.

Once it has been decided that research is the process of obtaining data, the problem of organising and administering a research organisation becomes easier. Basically, there are four main sources of data: from personnel in your own organisation; from literature, including patents; from other companies and organisations; and by planning and conducting experiments in the laboratory. The last-named method is usually the most expensive.

The most effective method of covering each subject is to assign one, or at the most two, subjects to one person so that he can concentrate his time and talents. For instance, one engineer may specialise on automatic riveting, another on transparent enclosures, another on fatigue testing, flash welding, etc. When data are needed on one of these

subjects, the research engineer can usually provide the answer from his own knowledge or he will know just where to find the data desired in available literature. He knows exactly the state of the art. He knows what is needed in various applications of his special field and is able to evaluate new thoughts and suggestions. He is capable of making tests and experiments to obtain additional data if necessary.

On the other hand, research engineers are not the only essentials for a productive research group. There must be provided adequate tools with which to work, including laboratory equipment, a carefully planned technical library, opportunity to meet and have discussions with others doing the same work, and skilled assistants to carry out details of the work. In order to obtain full effectiveness, research engineers must be properly supervised so that their work will be kept in proper relationship with the work of the company as a whole.

At Lockheed Aircraft Corp. engineering research is conducted in six categories classified under two main headings - Aerodynamic, and Structural Research. Because of its important relation to design, Aerodynamic Research has been set apart from the rest of the research organisation, and the chief of this division is directly responsible to the Chief Engineer. The other groups responsible for Mechanical, Electrical, Structural, Production and Chemical Research are under the supervision of a Director of Research, who is responsible to the Chief Structures Engineer.

The duties allocated to each of the research groups are : -

MECHANICAL RESEARCH : Mechanical and hydraulic research on the aircraft, covering such general problems as air conditioning, hydraulic operation of landing gear and control surfaces, pressurisation of cabins, mechanical design of superchargers and similar equipment, and the study of other problems encountered in stratosphere flying. At present this group is the largest of the various research groups.

PRODUCTION RESEARCH :—Production processes such as riveting, spot-welding, sheet metal forming, metal drawing, flash welding, tooling, heat treating, arc and torch welding, casting etc.

STRUCTURAL RESEARCH: Strength of materials, joints and other structural components; also research on sound, vibration and flutter. This group conducts static and dynamic tests on the completed aeroplane and conducts many static and dynamic tests on aircraft components.

ELECTRICAL RESEARCH : —Develops electrical methods of obtaining data, including electrical methods of measuring and recording stresses in structures or machine members, methods of measuring and recording temperatures in many applications, such, for instance, as in the interior of a spotwelder during the time the current is flowing. This group is also responsible for study of the electrical aspects of welding equipment, induction heat-treating equipment, etc.

CHEMICAL RESEARCH : Cleaning, painting, hydraulic fluids, processing plastics, fuels, etc.

Research engineers by themselves are of limited value. They must have extensive facilities and certain services available before they can function effectively. At Lockheed these facilities and services are under the supervision of a Laboratory Manager.

The problem of supervising research personnel is interesting, and special techniques are required. This is because, first, the personnel are of unusually high calibre ; second, the supervisor cannot possibly know as much about individual problems as the individual research personnel ; third, research engineers are of necessity honest and logical and deeply resent arbitrary decisions by superiors ; and fourth, because of the nature of their work, research engineers have to have more freedom and independence of action.

However, once these facts are recognised, supervision becomes easier. The research engineer's activities can be evaluated by periodic progress reports, by completed reports of his work, and by his notes. All notebooks are arranged so that two carbon copies are made of each page. Carbon copies can be removed at the end of each day and be sent to the supervisors, for information or action. The quality and quantity of work can thereby be quite accurately gauged.

One of the most useful and interesting methods for the executive control of research activities is the process of judicious sampling. It is not necessary that an executive sample the activities of every research engineer every day. However, if he makes frequent random checks on his personnel, he will assure himself he is spending his company's money in the most efficient manner. Incidentally, most of the money spent for industrial research is spent for salaries. Therefore, the efficient use of personnel is of paramount importance.

Aircraft industrial research co-operation is accomplished by several methods. There is direct exchange of technical information by personal contacts and by the exchange of reports. One of the most general means of exchanging information is through participation in meetings and the technical committee work of engineering organisations. Information is also disseminated by technical papers.

Three typical problems which are being considered not only by Lockheed but also by many other companies and individuals, should be mentioned. Considerable progress has been made, but there is still much to be achieved. The typical problems are :—

BLIND RIVETS :—Although several excellent devices are now commercially available, none as yet have met all the requirements for an ideal fastening that can be inserted and driven from the outside which will fill the hole completely, pull the sheets together automatically, and will be as strong as standard rivets, yet simple in operation, easy to drive, light and inexpensive to manufacture.

NON-DESTRUCTIVE TEST FOR SPOT-WELDS : -The apparatus must be small so that tests can be made on welds in obscure places, light so it can be readily transported, and inexpensive so it can be available to all who must inspect aircraft structures. It must be able to detect welds which are sub-standard even though they are close together, near the edge of a sheet, near large masses of other metals, covered with paint, or if they are in alloys of various grades and gauges. The development of such a device will be a real contribution to the engineering knowledge which is necessary before spot-welding can be used in many primary structural applications.

REMOTE CONTROL :—Although much has been done with hydraulic and electrical systems, further improvement is desired along the lines of reduced weight, simplicity, reliability, etc. A typical example is the " boost " required for the pilot of a large aeroplane. The ideal solution would be some method by which the pilot's strength is increased many times without any sacrifice in speed of operation or other control qualities of the small aeroplane.

29018

LIBRARY—LABORATORY RESEARCH

(Mech. Eng., Vol. 63, No. 5, May, 1941, pp. 381-382)

Costly repetition of research already described completely in the literature and failure to appreciate inventions described almost verbatim in the literature, will continue under present circumstances until the scientist gives to library research the attention it merits. Already the time has come when research programmes should provide a definite place for a new type of scientist. This scientist will devote all, or the greater part, of his time to thorough investigation of scientific literature. His research will be marked by the same thoroughness, concentration, imagination and resourcefulness as that of brother scientists in the research laboratories. He will guide laboratory programmes from the pitfalls of prior art. He will unearth innumerable inventions now hidden in the literature, and he or his fellow scientists will check those library discoveries by laboratory tests.

28407

OUR UNUSED POTENTIALITIES FOR AERONAUTICAL RESEARCH AND DEVELOPMENT

(J. E. YOUNGER, Mech. Eng., Vol. 63, No. 8, August, 1941, pp. 575-576)

Funds have been provided for practically every phase of aviation except the most important phase of all, i.e., the training of engineers whose business it will be to design and superintend the construction of those marvels of mechanism, the airplanes of the future, and to make those airplanes better than they can be made anywhere else in the world.

If additional educational training, for the aeronautical engineers who are to be the designers of the future air liners, is to be provided for, and certainly this will be absolutely necessary, funds must come from some other source, i.e., personal endowment, endowment by the industry, or endowment by the National Government.

Other aeronautical sciences are so far behind the science of aerodynamics in development, that practical use cannot be made of the new discoveries in aerodynamics. By all means the development of aerodynamics must not be slowed down, but other phases of the aeronautical sciences of equal importance should be given equal consideration or a balanced programme. The standard of aeronautical training and research in structures, materials, fabrications, and other phases of aeronautics must be brought up at least to the standard set for aerodynamics.

R.T.P. Ref. — *Title and Journal*

AIRCRAFT DRAWING OFFICE PROCEDURE

969 U.S.A. — *High Speed Developing and Printing Machines for Engineering Drawings.* (American Av., Vol. 5, No. 16, 15th Jan., 1942, p. 34.)

2452 Gt. Britain — *Photo Copying Methods in the Drawing Office.* (Engineer, Vol. 173, No. 4505, 15th May, 1942, pp. 415-416)

2914 U.S.A. — *Standardised Drawing Office Practice (for American Aircraft Industry).* (Airc. Prod., Vol. 4, No. 40, Feb., 1942, p. 216.)

3611 U.S.A. — *Photo Tracings. Their Use in Making Pictorial Blueprints.* (Lester C. Jones, Lockheed Aircraft Corporation, Paper No. 59.)

INTERCHANGEABILITY

28065 Gt. Britain — *Tolerance of Aircraft Parts.* (H. G. Conway, Aircraft Production, Vol. 111, No. 34, Aug., 1941, pp. 281-283.)

28798 Gt. Britain — *Interchangeability and Production Problems.* (B. Kaiser, Airc. Prod., Vol. 111, No. 36, pp. 376-381.)

TESTING AND INSPECTION METHODS

25833 Gt. Britain — *Application of Z-Rays to the Study of Alloys.* (H. Lipson, Nature, Vol. 146, No. 3712, 21st Dec., 1940, pp. 798-801.)

26273 U.S.A. — *X-ray Finds Flaws in Aircraft Parts.* (T. Triplett, Aviation, Vol. 40, No. 1, Jan., 1941, pp. 46-7 and 108.)

27059 Gt. Britain — *Inspection of Aircraft Components by X-rays.* (R. J. Tunnicliffe, Flight, Vol. 60, No. 1689, 8th May, 1941, p. 328, B/c.)

29515 U.S.A. — *Fairey Aviation Research Laboratory.* (Flight, Vol. 40, No. 1716, 13th Nov., 1941, pp. b-f.)

29406 Gt. Britain — *X-ray Analysis in Industry.* (The Metallurgist (Supplement to The Engineer), Oct. 31st, 1941, pp. 33-34.)

269 Italy — *Equipment of Material Testing Laboratory of Guidonia.* (G. Montelucci, Atti di Guidonia, No. 53-54, 20th June, 1941, pp. 205-236.)

1394 U.S.A. — *X-ray Examination of Aircraft Castings (Control and Value).* (B. C. Boulton, Inst. Aeron. Sci., 10th Annual Meeting, Jan., 1942, pp. 1-15.)

2480 U.S.A. — *X-ray Inspection.* (H. M. Muncheryan, Aviation, Vol. 41, No. 1, Jan., 1942, pp. 84, 184-186.)

2343 Gt. Britain — *X-ray Analysis in Industry (Inst. of Physics Conference).* (Electronic Engineering, Vol. 14, No. 171, May, 1942, pp. 753-754.)

2398 Gt. Britain — *Z-Rays in the Light Metal Industry.* (E. J. Turnicliffe, Light Metals, Vol. 4, No. 51, April, 1941, pp. 108-119.)

2431 Gt. Britain — *X-ray Analysis in Industry.* (Nature, Vol. 149, No. 3783, 2nd May, 1942, pp. 503-504.)

2840 Gt. Britain — *The " Optigage " Optical Comparator.* (Engineering, Vol. 153, No. 3988, 19th June, 1942, p. 486.)

2913 Gt. Britain — *Thermetric Colours.* (Airc. Prod., Vol. 4, No. 40, Feb., 1942, p. 216.)

3086 Gt. Britain — *Contour Projector for Inspection of Gauge and Thread Profile.* (Aircraft Production, Vol. 4, No. 43, p. 361, May, 1942.)

3185 Gt. Britain — *Inspection of Light Castings.* (F. A. Allen, J. Morgan, Airc. Prod., Vol. 4, No. 44, pp. 424-426, June, 1942.)

25709

MODERN AIRCRAFT MATERIALS AND THEIR TESTING

(K. R. Jackman, J.S.A.E., Vol. 47, No. 5, Nov., 1940, pp. 461-73 496)

The commonest steels used for the highly stressed parts of aircraft (landing gears, engine supports, etc.) are as follows:—

Material						Tension							Shear				
	Specifications		Form	Specific Gravity D	Weight Cu. In.	Ultimate		Yield		Mod. of Elas.		Elong.	Ultimate		Modulus of Rigidity G	Fatigue Limit	Cost $/lb.
No.	Army	Navy				T	T D	Y	Y D	E	E D	% in 2"	S	S D			
						$\times 10^3$				$\times 10^6$			$\times 10^3$		$\times 10^6$	$\times 10^3$	
Steel Alloys																	
1025	57-107-9B	46-S-22	Bar	7.8	.28	55	7.1	36	4.6	28	3.6	22					
2330	57-107-17b	46-S-21b	Bar	7.8	.28	125	16.0	100	12.8	29	3.7	17					.15
X4130	57-107-19b	46-S-23E	Bar	7.8	.28	150	19.2	135	17.3	29	3.7	18	100	12.8	11	78	.15
4345	11062	46-S-28	Sheet	7.8	.28	230	29.5	220	28.2	30	3.9	4			11	95	
Stainless Steel Alloys																	
18-8	57-136-9	47-S-19	Sheet	7.8	.28	80	10.2	35	4.5	26	3.3	40	70	9.0		30	70
18-8	11068	47S21½H	Sheet	7.8	.28	150	19.1	110	14.0	26	3.3	10	100	12.8		35	70
18-8	10079	46S18-1C	Bar	7.8	.28	120	15.3	60	7.7	30	3.9	15					55
18-8	10079	46S18-7E	Bar	7.8	.28	100	12.8	50	6.4	29	3.7	28					55
16-2		M-286	Bar	7.8	.28	175	22.4	135	17.2	30	3.9	13					50

3209 U.S.A. — *X-ray Examination of Castings.* (Aero. Digest, Vol. 40, No. 5, pp. 209, 357, May, 1942.)

2929 U.S.A. — *Inspection of Aircraft Components by X-rays.* (R. C. Woods and T. M. Nolan, Iron Age, Vol. 147, No. 24, 12th June, 1942, pp. 46-49.)

3405 U.S.A. — *Gauges and Gauging Procedure.* (G. M. Simpson, Am. Soc. Nav. Eng., Vol. 54, No. 2, May, 1942, pp. 273-279.)

4938

INSPECTION BY SAMPLING—EFFECT OF NUMBER OF SAMPLES TO BULK NUMBER

(R. H. Parsons, Engineering, Vol. 154, No. 4004, 9th Oct., 1942, pp. 294-295)

The probability that a sample of m articles taken from a bulk of m articles of which p are defective will fail to include any defectives at all can be computed from the formula

$$\frac{(m - p)^{1}\,(m - n)^{1}}{(m^{1}\,(m - p - n)^{1}} \qquad (1)$$

where ¹ indicates the factorial operation.

The probability that it will comprise exactly A good articles and B bad ones is given by

$$\frac{n^{1}\,p^{1}\,(m - p)^{1}\,(m - n)^{1}}{A^{1}\,B^{1}\,(m - p \quad A)^{1}\,(p - B)^{1}\,m^{1}} \qquad (2)$$

From (1) it is easy to calculate the size of the sample required for any assigned odds in favour of the sample affording evidence of the bulk falling below some specified standard of quality.

Thus, if a 2 : 1 probability is required that a bulk of a 1,000 articles does not contain more than 45 defectives, the sample must contain at least twenty-four articles, i.e., we expect a sample of twenty-four containing no defectives will not be drawn from the bulk more than once in three times.

Similarly a 10 : 1 assurance would require a sample of fifty-one articles. If none of these contain any defectives we have the required expectation that the bulk contains less than forty-five defectives.

The following table gives the size of samples required to detect the presence of more than 5% defectives in batches of different numbers for various degrees of assurance :—

No. of articles in batch	20	100	200	300	400	500	1,000
Size of sample for even chance of detection*)	10	13	14	14	14	14	14
Size of sample for 10 : 1 chance ..	18	38	42	44	45	45	46

*As the sample cannot consist of fractional numbers, the constant size (14) for batches from 200 to 1,000 really corresponds to a probability decreasing from 1.12 : 1 to 1.06 : 1.

25709

MODERN AIRCRAFT MATERIALS AND THEIR TESTING

(K. R. Jackman, J.S.A.E., Vol. 47, No. 5, Nov., 1940, pp. 461-73, 496)

From a quick glance at some of the newer aircraft materials and test procedures, we find that the high-tensile aluminium alloys still hold the structural field, although crowded a little by some of the magnesium alloys. The alloys of beryllium hold only minor structural promise, but the pure beryllium metal may have a future for armour plate in planes. Chrome-molybdenum steel maintains its favoured position but it has lost some ground to the stainless steels, especially of the heat-treatable " M. 286 " variety. Plastic and wood-and-plastic construction probably will not immediately replace light metal construction. Thermo-plastic windows with their weight-savings, are edging out those of laminated glass, but should be tested carefully for pressurised cabin uses.

The pre-stretching of aluminium alloy stiffeners offers a method of gaining strength at no cost in weight or price. Pre-compressing, theoretically of great promise, runs into practical shop difficulties on application.

The electric resistance strain gauge of the Celstrain or Baldwin-Southwark type promises to add new impetus to practical full-scale testing and research at one-tenth of the instrumentation cost of former remote-recording extensometers.

SAE 4345, a Ni-Cr-Mo steel, suitable as substitute for the usual Cr-Mo steel, has good depth-hardening qualities, making it suitable for high-strength forged fittings. It may be heat-treated to over 200,000 lbs. per sq. inch, and the excessive hardness produced by welding can also be neutralised by heat treatment. Scaling during heat-treatment is now largely overcome by use of an anti-scaling compound " Galvo."

Stainless steels are divisible into two groups:—(1) Those not suitable for heat-treatment but which obtain their qualities from cold-working, and (2) those that can be heat-treated. The first group, which includes the " 18-8 " types, contain low carbon, 17-25% Cr and 7-13% Ni—and are usually non-magnetic. The second, heat-treatable group consists of magnetic steels containing 12-18% Cr, approximately 2% Ni and up to 1% C.

The conventional heat-resisting steel for aero-engine exhaust collectors is a titanium stabilised 18-8 product, Navy designation " 47S19."

Particular uses and treatments of the various grades of aircraft are briefly mentioned.

954 NON-DESTRUCTIVE TESTING

(Autom. Eng., Dec., 1941, pp. 448-50)

Principles of operation and brief outlines of apparatus used in non-destructive methods of testing welds, castings, etc., are given. By placing the rubber-capped cone of a stethoscope against the work whilst the latter is tapped with a hammer, the natural period note of the part can be heard when it is free from defects. Portable tensile testing machines are reviewed. Magnetic and electrical testing methods may be employed, and it is shown how permanent records from the former method may be obtained. Particulars of X- and Gamma-ray testing are given, and in explaining the interpretation of radiographs, some industrial X-ray plants are reviewed.

(Abstract supplied by Research Dept., Met.-Vick.)

5590

EFFECT OF RIVET AND SPOT-WELD SPACING ON THE STRENGTH OF AXIALLY LOADED SHEET—STRINGER PANELS OF 24 S-T Al. ALLOY

(S. Levy and others, N.A.C.A. Tech. Notes, No. 856, August, 1942)

Eighteen 24S-T aluminium-alloy sheet-stringer panels were tested in end compression under carefully controlled edge conditions. The stringers were fastened to the sheet by brazier-head rivets spaced 0.5 inch to 6 inches between centres for nine of the panels, by spot welds spaced 0.5 inch to 4 inches between centres for six of the panels, and by round-head rivets spaced 0.5 inch to 2 inches between centres for the other three panels.

In the tests of the panels with stringers fastened to the sheet by brazier-head rivets and by spot welds, measurements were made of the stringer strains and of the buckling deflections of the sheet. In the tests of the three panels with round-head rivets only the buckling loads and ultimate loads were measured.

The buckling load and the deflection of the sheet between rivets and spot welds were compared with Howland's theory. The buckling load of the sheet between stringers and the deflection of the sheet between stringers were compared with Timoshenko's theory. Most of the observed buckling loads and deflections were in agreement with these theories and indicated that the two types of buckling were substantially independent of each other for the specimens tested.

Four of the panels with brazier-head rivets and three of the panels with spot welds failed by separation of rivets or spot welds at stringer stresses of 24.2 to 39.5 kips per sq. inch. The other panels failed by stringer instability at a stringer stress between 37.0 and 42.0 kips per sq. inch.

The observed effective widths of the sheet between stringers were from 8% lower to 20% higher than those calculated from Marguerre's approximate formula up to an edge strain at which buckling occurred between rivets or spot welds. The sheet load remained approximately constant after buckling of the sheet between rivets or spot welds.

A nomogram was devised for calculating the load for failure by stringer instability of panels of the type tested as a function or rivet of spot-weld spacing, stringer spacing, reinforcement rate, and critical stringer stress.

For the eleven panels that failed by instability of the stringers the observed strengths at failure were within 6% of those calculated from the nomogram; for the seven panels that failed by rivet and spot-weld fracture the observed strengths were from 2 to 24% below the calculated values for stringer instability. The estimated loss in strength because of failure of rivets or spot welds exceeded 6% for only two panels for which the average sheet stress at failure was between 10.0 and 25.0 kips per sq. inch. No significant differences were found in the strength of panels fabricated with brazier-head rivets, spot welds, or round-head rivets.

26751 **A MICRO-HARDNESS TESTING MACHINE**

(HANEMANN, Engineers Digest, Feb., 1941, pp. 42-44)

Hardness testing by Brinell, Rockwell and Vickers methods affect a large number of crystals and hence the distribution, magnitude and quantity of the crystals influence the result. Previous microscope hardness measuring tests, it is stated, have been limited to scratch and abrasive methods, which, however, measure rather the resistance to wear than the plastic deformation. This new micro-hardness testing device has the indentor unified with the lens and is claimed to be very simple to handle. The surface of the sample is brought into focus and the sample so arranged that the crystal to be tested comes in the correct position. The objective is then lowered on to the specimen until the test load is reached. Measurement of the impression follows.

(*Abstract supplied by Research Dept., Met.-Vick.*)

29197

AUTOMATIC MAGNETIC CRACK DETECTOR

(E. A. W. MULLER, E.T.Z., Vol. 62 (1941), No. 30, pp. 653-658) (Reviewed in Z.V.D.I., Vol. 85, No. 37-38, 20th Sept., 1941, pp. 788-789)

The cost of magnetic crack detection in small parts is largely a question of the time taken in setting up the specimen. The author describes a machine which carries out all the manipulation automatically, provided the specimens are all cylindrical and of the same size (e.g. gudgeon pins). The pins are transferred in succession to end grips, magnetised, rotated and sprayed with oil containing metal filings. After a definite time interval the oil spray is stopped and the current cut off. The specimen continues to rotate slowly, the inspector operating a button which automatically unclamps the specimen and allows it to drop into the " pass " or " reject " box. A new specimen is then introduced automatically and the cycle repeats. The inspector sits in comfort in front of the apparatus and can give his whole attention to the examination, without being distracted by any mechanical work.

2753

EFFECT OF MAGNETIC FIELD DISTRIBUTION IN MAGNETIC INSPECTION

(F. L. FULLER, J. Aeron. Sci., Vol. 9, No. 6, April, 1942, pp. 202-206)

The present wide use of magnetic testing for flaws in parts made of magnetic metals has given rise to many problems because of the complex shape of the parts. In many instances regions of intense magnetic saturation occur in such a way that very slight variations in surface structure such as those due to forging will give very strong indications while adjacent regions not magnetically saturated are substantially free of indications. It is the purpose of this paper to describe an investigation of this phenomenon in an eccentrically cylindrical crank pin section of an aircraft engine crankshaft.

By the insertion inside the pin of a suitable eccentric sleeve of the same material as the crankshaft, the structure can be made practically symmetrical. The field will be uniform throughout the volume and surface flaws of a given magnitude will be visible to the same degree on any part of the periphery.

26880

AN EDDY-CURRENT METHOD OF FLAW DETECTION IN NON-MAGNETIC METALS

(R. GUNN, J. App.Mech., Vol. 8, No. 1, March, 1941, pp. 22-26)

An equipment suitable for the location of surface or submerged flaws in non-magnetic metals is described. A predetermined pattern of electrical eddy currents is induced in a perfect test sample by alternating magnetic fields. Sensitive pick-up coils properly

disposed in relation to the eddy currents measure only the departures of the eddy-current pattern from the pattern in the perfect sample. The departures are indicated on a meter or may be recorded. Performance data are given for a universal type of search unit especially adapted for general surveys.

30055

MAGNETIC POWDER-ETCHING FOR CRACK DETECTION

(I. and Coal T. Rev., 25th July, 1941, p. 73)

Particulars are given of methods used in Germany for the magnetic testing of metallurgical objects. The article is abstracted from a report published in "Stahl und Eisen." Apparatus for the test using an oil film with iron filings in suspension and apparatus for the magnetic impulse type of testing have been developed. Considerable attention is paid to the interpretation of diagrams, magnetising conditions and to the effect of direction of magnetisation. It is finally concluded that magnetic etching or spraying should be supported by additional metallographic investigation to verify the presence of flaws and cracks.

(Abstract supplied by the Research Dept., Met.-Vick.)

28202

X-RAY ANALYSIS IN INDUSTRY

(J. Sc. Inst, July, 1941, pp. 126-158)

The second part of this Symposium is reproduced in this issue and is devoted to the technique of X-ray analysis methods and some recent developments. Thirteen papers are recorded and include the following :—Photometry of X-ray crystal diffraction diagrams; simple photometer for the examination of X-ray films; Experimental technique in the study of alloys by X-rays; X-ray crystal photography at low temperatures; Measurement of stress by X-rays; Some applications of X-ray methods in the examination of organic crystals; The derivations of lattice spacings from Deby-Scherrer photographs; Systematic determination of crystal orientation; Some applications of X-ray technique to the study of preferred orientation of crystals in metals; Superlattices, X-ray diffraction and the deformation of metals; Precipitation in the solid state, and Particle size measurement by the X-ray method.

(Abstract supplied by Research Dept., Met.-Vick.)

29593

X-RAY EXAMINATION OF MG. ALLOY CASTINGS

(H. T. Rupprecht, Luftwissen, Vol. 8, No. 9, Sept., 1941, pp. 283-286)

X-ray examination of Mg. Alloys is rendered difficult by the small absorption coefficient of the material coupled with a considerable amount of scattering of the radiation. The latter becomes the more marked the shorter the wave length of the incident radiation, i.e., the higher the tube voltage. For work of this kind, therefore, it becomes necessary to generate X-ray at relatively low voltage and ensure sufficient penetration by increasing the tube current. Unfortunately, commercial X-ray apparatus are generally designed for voltages of the order of 250 K.V. (20m. amp.) and cease to generate if the voltage is reduced below 50 K.V. At the same time the tubes normally employed will not pass on increased current to make up for the voltage reduction. According to the author, special apparatus has now become available which will generate X-rays at 24 K.V. (4 m. amp.) and pass 30 m.a. at 100 K.V. With this equipment, examination of Mg. alloys can be carried out with the same degree of accuracy as for Al. alloys. The new apparatus is, however, necessarily expensive and can only justify itself if exclusively and continuously employed on Mg. alloys. As an alternative quite good results can be obtained with standard equipment if a special photographic film of ultra-fine grain and steep gradation is employed. The new film is relatively insensitive to scattered radiation and its superiority in detecting faults is illustrated by a number of sample photographs.

27461

A NEW USE FOR X-RAYS IN INDUSTRY

(Woods and Kenner, Electronics, April, 1941, pp. 29-31)

Particulars are given of an industrial process which uses the ionisation of air caused by the presence of X-rays to pass a minute current which controls a pass-or-reject relay. This new process is automatic in operation and it is suggested that for inspection of large numbers of articles it will prove more efficient and practical than the normal fluorescent inspection methods. The apparatus described is stated to be readily capable of inspecting 1,400 table knives an hour.

(Abstract supplied by Research Dept., Met.-Vick.)

27500

X-RAY ANALYSIS IN INDUSTRY

(J. Sci. I., May, 1941, pp. 69-102)

This issue contains the first part of a Symposium on X-ray Analysis in Industry sponsored by the Institute of Physics. The industrial applications of X-ray Analysis form the subject matter for the ten papers in this section and included are such titles as: Some Application of the X-ray Powder Method in Industrial Laboratory Problems; An X-ray Examination of Mechanical Wear Products, and Some Examples of Industrial Testing of Materials by X-ray Diffraction. The second part of the Symposium is planned to be published in the July issue.

(*Abstract supplied by Research Dept., Met.-Vick.*)

25264

APPLICATIONS OF X-RAY TECHNIQUE TO INDUSTRIAL LABORATORY PROBLEMS

(H. P. Rooksby, G.E.C. Journal, Vol. II, No. 2, August, 1940, pp. 83-95)

The author attempts in this paper to give some idea of the various ways in which the X-Ray crystallographic method of examination has been used in an industrial laboratory. Many of the illustrations chosen have emphasised how X-ray methods give information which cannot be obtained by chemical means, but there is no doubt that the most instructive solution to a problem is reached only by utilising all the methods of investigation at our disposal. We must also envisage the addition of new instruments to reveal yet further properties of materials, and the method of electron diffraction may be mentioned as being better suited to the examination of surface phenomena than X-ray analysis. On the other hand, it is not always realised how wide is the scope of X-ray analysis, and how certain physical properties such as coefficient of expansion which have been measured in the classical manner have also been measured by X-ray methods. Such new measurements should not be regarded merely as repetitive, for new aspects of the physical property may be revealed by a fresh method of approach.

New conceptions are arising directly out of the recent measurements on lattice distortion and the lower limiting size of crystallites developed in a cold worked metal, and the gradual clarification and development of our picture of the ultimate structure of matter owes much, and will owe still more in the future, to the revealing and searching power of X-rays.

3958

X-RAY OF AIRCRAFT CASTINGS—CONTROL VALUE

(B. C. Boulton "J. Aeron. Sci.," Vol. 9, No. 8, June, 1942, pp. 271-283)

(1) For certain important classes of material X-ray inspection is a valuable tool. Its most important function is the creative one of aiding in the initial development of correct design, dies or patterns, and foundry technique. Its second basic function is that of maintaining a continuing control over foundry practice to insure maintenance of quality. It is not considered a suitable means for large-scale routine inspection where this is the only purpose served. An important exception to this last statement is the class of vital structural parts with a low ratio of breaking load to design load, which may well be X-ray-inspected 100% until further progress is made in foundry control.

(2) Defects that can be revealed by X-ray have a marked detrimental effect on the impact and fatigue properties of castings, much greater than the effect on static strength. With skilled and careful inspection, there is a reasonably good correlation between these properties and the quality of a radiograph.

(3) The standards for rejection by radiographic inspection should be based not on the absolute value of the casting quality but on airworthiness considerations and should take cognisance of the ratio between the actual strength of a sound casting and its design load, and also whether the part is subject to unusual conditions of impact or fatigue. A definitely higher X-ray quality should be required for castings with minimum strength factors or those subject to definite impact or fatigue loading. Two or possibly three quality standards should be set up, and the individual having responsibility for rejection must know the quality standard applicable to each casting. Parts subject to impact and fatigue should meet a high-quality standard.

25783

TENSOR GAUGE

(Inter. Avia., No. 731, 12th Oct., 1940, p. 12)

With the introduction of the all-metal monocoque type of construction in the aircraft industry, it was found necessary to develop a method of determining in a simple way the complete state of strain and stress in continuous sheets of thin plates under the influence of loads in the aeroplanes. The conventional experimental procedure consists of applying linear strain gauges in different directions during three successively repeated load cycles. The technical difficulties of repeating the test load cycle with exactly the same load distribution are well known. The efforts to develop a handy instrument which permits simultaneous measurement of stresses in three directions on certain points of the fuselage monocoque, at inaccessible junctions, etc., have led to the design of the Tensor Gauge. The instrument is fastened to the specimen surface by a single central suction cup; three measuring cones, entirely independent of each other and forming the corners of an equilateral triangle, engage the specimen in a circular diameter of 30mm. Each of the three movable legs is guided precisely radially; their movements are translated with imperceptible friction to a microscopic index reticule, the position of which is made readable by means of magnifying lenses. A strain of 1-10,000, which in aluminium corresponds to a linear stress of approximately 1,000 lbs. per sq. inch, appears as one scale division; the total range amply covers any test requirements within the yield limits of the structural material.

25421

MODERN MEASURING INSTRUMENTS

Dr. G. SCHLESINGER, Machinery, 3rd Sept., 1940, p. 12)

The author concludes this outline of features of modern measuring instruments and principles of their design with a review of optical alignment testers and micro-comparator gauges. Optical alignment testing comprises the telescope and target method, the sighting telescope and collimator methods and the use of the auto-collimator. Under micro-comparators the author describes the electrolimit gauge and the solex pneumatic micrometer. Each instrument is described in some detail, with illustrations of commercial types, and the accuracy attainable is noted.

Illustrated with six photographs and eleven diagrams.

R.T.P. Ref.	*Title and Journal* **MODERN APPLICATIONS OF AIRCRAFT MATERIALS**
26521 Gt. Britain	*Choice of Aircraft Materials for Aircraft Construction.* (F. T. Hill, Aeronautics, Vol. 4, No. 2, March, 1941, pp. 34-36.)
28826 Gt. Britain	*Improvements in Manipulation of Metal Powders.* (G. J. Comstock, Metal Industry, Vol. 59, No. 10, 5th Sept., 1941, pp. 149-150.)
60 Gt. Britain	*The Manufacture of Articles from Powdered Metals.* (W. D. Jones, Engineering, Vol. 152, No. 3963, 26th Dec., 1941, pp. 515-516.)
30115 Germany	*The Utilisation and Surface Protection of Light Metals in Aircraft Construction.* (Der Flieger, Vol. 20, No. 7, July, 1941, pp. 230-231.)
2483 U.S.A.	*Beryllium Alloys in Aviation.* (E. Burke Wilford, Aviation, Vol. 41, No. 1, Jan., 1942, pp. 92-93, 188.)
2757 Gt. Britain	*Non-Priority Materials in Aircraft Construction.* (Flight, Vol. 41, No. 1746, 11th June, 1942, pp. 590-591.)
2852 Gt. Britain	*Beryllium, Its Economics and Technology.* (W. F. Chubb, Light Metals, Vol. 4, No. 52, May, 1942, pp. 156-164.)
2920 Gt. Britain	*Malleable Beryllium.* (G. E. Claussen and J. W. Skelan, Metal Industry, Vol. 61, No. 1, 3rd July, 1942, pp. 10-12.)
3192 U.S.A.	*Use of Steel and Wood to Conserve Al. in Aircraft Construction.* (Aero. Digest, Vol. 40, No. 5, pp. 127-130, 272-274, May, 1942.)

R.T.P. Ref.	Title and Journal
3291 Gt. Britain	*Powder Metallurgy (Fabrication of Sintered Parts).* (Autom. Eng., Vol. 32, No. 425, July, 1942, pp. 266-268.)
3510 U.S.A.	*Powder Metallurgy—Sintering of Iron.* (J. Libsch and others, Metal Progress, Vol. 41, No. 4, April, 1942, pp. 528-530 and 540 and 550.)
3651 Gt. Britain	*Bibliography of Published Information on Powder Metallurgy.* (R.T.P.3, Bibliography, No. 52, 15th July, 1942.)

265

BERYLLIUM AS A LIGHT METAL COMPONENT

(C. B. Sawyer, The Metallurgist (Supp. to Engineer), 26th Dec., 1941, p. 48)

The Brush Beryllium Company (U.S.A.) has developed methods of production of the metal of guaranteed purity 96%, which may be raised to as high a value as 99.94%. Sawyer and Kjellgren recorded the properties of 99.5% beryllium, the impurities being aluminium, iron, magnesium, carbon and silicon. Its density was 1.84, specific heat 0.475, and linear coefficient of expansion 13.3×10^6. In the cast condition it had a tensile strength of 7.6 to 9.3 tons per sq. inch, and elongation nil. As forged at 900-1,000° C. (0.75 inch to 0.36 inch diameter), its tensile strength was 13.3 tons per sq. inch, and, after annealing at 1,000° C. in hydrogen, 12.0 tons per sq. inch, the specimens in both cases breaking with no measurable elongation. Determinations of the modulus of elasticity gave results varying from 42.6×10^6 lbs. per sq. inch for the cast alloy to 36.8×10^6 lbs. per sq. inch for the forged and annealed bar. The only practical use suggested for the pure metal is to replace aluminium as " windows " for X-ray tubes, beryllium being said to be seventeen times as penetrable to X-rays as is aluminium.

For the past four or five years the Aluminium Company of America, in co-operation with J. B. Johnson, Chief of the Materials Laboratory of the War Department, Wright Field, and with the Brush Beryllium Company, has been carrying out an extensive investigation of beryllium-aluminium alloys, aimed at the production of a better piston material.

In general the alloys possessing a moderate elongation have nothing in their favour except a high modulus of elasticity (14 to 16×10^6 lbs. per sq. inch, as compared with about $10 \times 11'$ lbs. per sq. inch for aluminium alloys). This is not sufficient to compensate for their lower strength at room temperature, though at 600° F. their tensile properties are more favourable. There are also serious casting difficulties and the author concludes that there is no future for Be-Al. alloy.

26126

TITANIUM AND SOME PROPERTIES OF CR-MO. STEEL FOR AEROPLANE TUBING

(G. F. Comstock, Metals and Alloys, July, 1940, pp. 21-26)

In these forged and normalised S.A.E. X 4130 steels, welded lengthwise, machined flat and bent cold with the weld outside, the presence of titanium improved the bending quality even when accompanied by higher manganese or 0.31% Cu. Steels with 0.15% Ti. and with 0.09% Ti. and 0.31% Cu. bent most easily after welding, without cracking. Presence of over 0.1% Ti. in these samples produced a softer steel but did not decrease the degree of hardening by welding. With 0.85% Mn. and 0.093% Ti. the steel was harder than with the normal manganese content but there was no greater hardening by welding than in the untreated steel. The microstructure showed a narrower hardened and coarsened zone in the titanium steels than in the untreated, especially without copper or increased manganese.

Improved ductility, impact value and microstructure produced by titanium or Ti. + Al. in the normalised test-bars is reflected by a similar improvement in the weld-bend tests. With the manganese increased to about 0.85% and 0.09–0.10% Ti. in this S.A.E. X 4130 steel the strength in the normalised condition is satisfactory, the hardening by welding is not excessive, and the ductility after welding and resistance to impact are definitely improved as compared with the regular or untreated X 4130 steel. The investigation is described and results of welding tests are summarised.

29723

INDIUM IN AGE-HARDENABLE ALUMINIUM ALLOYS

(W. H. Fraenkel, Metal Industry, Vol. 59, No. 21, 21st Nov., 1941, p. 332)

In the course of investigations on the effect of indium on various alloys it was found that small amounts of indium have a marked influence on age hardenable aluminium alloys.

The alloys of the duralumin type which age at room temperature do not become harder with the addition of indium, although the rate of hardening is considerably lowered.

On the other hand, alloys without magnesium show a marked increase in hardness with the addition of indium as shown in the table.

Effects of Indium on Age Hardening of Aluminium-Copper Alloys

Alloy No.	Without Indium			With 0.05% Indium		With 0.1-0.2% Indium	
	Composition	Max. B.H.N.	Increase during ageing	Max. B.H.N.	Increase during ageing	Max. B.H.N.	Increase during ageing
A	Al + 4-4.5% Cu.	93, 93 87, 95 86, 82	32	110	56	114, 124 109, 125 109, 125	63
		ave. 89				Ave. 116	
			34	117	62	126	67
		113, 109	36	114	47	119	38
D	Al + 4.5-5% Cu. + 1% Mn.	ave. 111	38	116	42	122	41

In the alloys mentioned the hardness after quenching is low, allowing easy deformation by mechanical means. The increase in hardness during ageing is remarkably high. This fact, as well as the other that hardening takes place at a slower rate in the duralumin type of alloys and at a faster rate in alloys without magnesium, may be of technical interest.

26409

IRON-BASE HARD-FACING METALS

(V. E. Alden, Mech. Eng., Vol. 63, No. 2, Feb., 1941, pp. 149-151)

An outstanding development of the last four years in the field of hard facing has been the development of iron-base alloys, containing chiefly the relatively less costly constituents, iron, chromium, nickel, molybdenum, and carbon. The wearing qualities of these alloys in the presence of temperatures up to at least 1350° F. are equal or superior to those of the cobalt-chromium-tungsten alloys, made up of more expensive constituents. This family of iron-base alloys goes under the name of "Coast Metals."

Excellent control can be exercised over these iron-base alloys to give all sorts of interesting properties. Various coefficients of expansion are obtainable by slight modifications of the basic analysis and thus hard surfacing of cylindrical sections of all types of steels and irons can be guaranteed free from checks or cracks.

One respect in which the experience with these iron-base hard-facing alloys differs from the experience outlined for the cobalt-chromium-tungsten alloys is that a majority of the applications have been made by arc welding. There are, however, a limited number of applications, such as the hard facing of the cutting edges of shears and dies, where Coast Metals can usually be best applied by gas.

25283

USE OF CLAD METALS IN GERMANY

(W. Radeker, Metal Progress, Vol. 38, No. 3, Sept., 1940, pp. 292-293)

Cladding is the term employed for the bonding of a nobler metal to a less noble base. This leads not only to the conservation of strategic materials, but the bonded product may have qualities which are superior to those of either of its constituents.

Considerable use is made of cladding on a steel sheet base, the following metals being used for the covering :—

Copper, Nickel, 18.8 Chromium Nickel or a special scale and creep resistant steel.

The most common method of manufacture is by rolling at the welding temperature. Ordinary steel and stainless steel can be bonded by a duplex casting process. The bonding of steel and aluminium is complicated and not yet in commercial use for chemical apparatus.

Methods have been devised for evaluating the adhesive strength of such coatings. Some of the results obtained with a mild steel base are given below :—

Silver	21,000 lbs. per sq. inch
Copper	28,500 ,, ,, ,, ,,
Nickel	34,000 ,, ,, ,, ,,
18.8 stainless	35,500 ,, ,, ,, ,,

Welds in coated materials completely satisfy the requirements of tightness, mechanical strength and chemical stability. In general the base metal is electric arc welded, using covered electrodes. The seam is then thoroughly cleaned and the coated side welded, using the coating material.

An interesting recent application of bi-metal plates is in the construction of heavy duty bearings. The coated plate is bent into the required shape and a special supplementary metallurgical treatment secures the required anti-friction properties.

R.T.P. Ref.	*Title and Journal*
	STEEL
25926 U.S.A.	*Stainless Steel—The Next Step for Aircraft.* (W. B. Stout, Metal Progress, Vol. 38, No. 4, Oct., 1940, pp. 461-2.)
29031 U.S.A.	*Stainless Steel Fabrication.* (Aviation, Vol. 40, No. 7, July, 1941, pp. 48-49.)
29345 U.S.A.	*Fabrication Considerations when Selecting a Steel : Forgeability, Cold Working, Welding, Flame Cutting, Machineability, etc.* (G. T. Williams, Metal Progress, Vol. 40, No. 3, Sept, 1941, pp. 289-292 and 378-382.)
2864 Gt. Britain	*Machineability of Steels.* (Autom. Eng., Vol. 32, No. 424, June, 1942, p. 236.)

5493

TENSION AND COMPRESSION STRESS-STRAIN CHARACTERISTICS OF COLD ROLLED AUSTENITIC CHROMIUM-NICKEL AND CR-MN-NI STAINLESS STEEL

(R. Franks and W. O. Binder, J. Aeron. Sciences, Vol. 9, No. 11, Sept., 1942, pp. 419-438)

The paper gives information on the stress-strain properties of the steels in both the longitudinal and transverse directions to rolling and shows the improvement obtained in these properties by application of the low temperature (200° to 300° C.) stress-relieving heat-treatment. It further shows that the 17% chromium, 7% nickel steels, and the 17% chromium, 5.50% manganese-4.50% nickel steels have better tension and compression properties longitudinal to the direction of rolling than do the 18% chromium-8% nickel steels, particularly when the steels are cold-rolled to a tensile strength exceeding about 150,000 lbs. per sq. inch. All these steels have better compressive properties transverse to the direction of rolling than longitudinal to the direction of rolling, but this difference is less marked in the 17% chromium-7% nickel steels and the 17% chromium-5.50% manganese-4.50% nickel steels than in the 18% chromium-48% nickel steels. An attempt has been made to present the data on the steels so they will be of greatest value to the designer of lightweight high-strength structures.

27824

SURFACE HARDENING BY INDUCTION

(Osborn, Engineer, 6th June, 1941, pp. 372-3

It is claimed that phenomenal advances have been made in the application of high-frequency current to the localised surface hardening of metals. Among the advantages claimed for the process are absence of distortion and scale formation, exact repetition

of conditions and an inherent increase in quality coupled with a decrease in cost. The questions of carbide diffusion and super-hardening are investigated and a brief description is given of the equipment employed in the various operations.

765 **OXY-ACETYLENE FLAME HARDENING**

(MAGRATH, Machinist, 10th Jan., 1942, pp. 958-60)

In flame hardening, the degree of hardness is said to be directly dependent upon the analysis of the metal (carbon being the principal hardening element) and upon the rate of quench. The author shows the theoretical relation between Brinell hardness and carbon content in carbon steel, based on a comparison of hardness acquired by small specimens as annealed, and as water quenched after furnace hardening. In general, higher hardnesses are obtainable on large objects by flame hardening than by furnace hardening. The importance of the nature, velocity and position of the quench in flame hardening is stressed, and advice in regulating and positioning the quench is given. The effect of different quenching mediums on hardness is discussed, and results obtained are compared.

28411 **SURFACE HARDENING BY INDUCTION**

(Mechanical Engineer, Vol. 63, No 8, August, 1941, pp. 602-603)

The heating is accomplished by the use of high-frequency currents. Specifically chosen frequencies from 2,000 to 10,000 cycles are being used extensively at the present time. Currents of this nature, when caused to flow through an inductor, will produce a high-frequency magnetic field within the region of the inductor. When a magnetic material such as steel is placed within this field, there is a dissipation of energy in the steel both due to hysteresis and eddy currents. Due to the well-known skin effect, the heating is limited to the outside layers.

When the temperature of an inductively heated steel bar arrives at the critical value, all heating due to hysteresis ceases and that due to eddy currents continues at a greatly reduced rate. Since the entire action goes on in the surface layers, only that portion is affected. The original core properties are maintained and the surface hardening is accomplished by quenching when complete carbide solution has been attained in the surface areas. Continued application of power causes an increase in depth of hardening, for as each layer of steel is brought to temperature the current density shifts to the layer beneath, which offers a lower resistance. It will at once be obvious that the selection of the proper frequency and control of power and heating time will make possible the fulfilment of any desired specifications of surface hardening.

Induction hardening produces a hardness which is maintained through 80% of its depth and from there on toward the core, a gradual decrease through a transition zone to the original hardness of the steel as found in the core which has not been affected. The bond is thus ideal, eliminating any chance of spalling or checking.

In addition to the selective surface hardening of steels, there have been other applications of induction heating of rather a unique nature. Hardening a piece of steel and brazing to copper and other metals may be done simultaneously. A small section of a previously hardened object can be drawn or softened to a condition possessing ready machineability. Heating for forging and upsetting has been found to be a particularly satisfactory use for induction heating. The speed with which this may be accomplished has made it readily adaptable to the high production requirements of forming equipment, and scale problems are reduced to a minimum. The corresponding increase in die life is of extreme importance. Tip annealing of brass cartridge shells at the rate of 100,000 per hour is provided with a single induction-heating unit.

R.T.P. Ref.	*Title and Journal*
	ALUMINIUM AND ALLOYS
29889 U.S.A.	*Al. Bronzes Commonly Used in Aircraft (Chart).* (Metal Progress, Vol. 40, No. 4, Oct., 1941, p. 437.)
29896 U.S.A.	*Welding Alclad.* (Metal Progress, Vol. 40, No. 4, Oct., 1941, pp. 656.)
484 Gt. Britain	*Al. and Mg. in Aircraft Construction (Foundry and Casting Practice). (Bulletin du Service Technique, France, B.S.T. No.* 92.) (R. de Fleury, Airc. Eng., Vol. 14, No. 155, Jan, 1942, p. 22.)

745 U.S.A. *Strengthening Al. for Aircraft Structures (from the U.S.A.).* (R. R. Jackmann, Metal Industry, Vol. 59, No. 11, 12th Sept., 1941, pp. 162-164.)

2285 Gt. Britain *Al. Alloys in Modern Warfare.* (P. M. Haenni, Metal Industry, Vol. 60, No. 19, 8th May, 1942, pp. 325-326.)

1398 **ALUMINIUM ALLOYS FOR AIRCRAFT**

(T. L. FRITZLEN, Inst. Aeron. Sci. 10th Annual Meeting, January, 1942, pp. 1-30)

The manufacture of aluminium from bauxite is discussed briefly as are re-melting and casting. The effect of working, alloying, annealing and heat treating is covered to the extent necessary to give a general picture of these factors. Methods used to determine mechanical properties and definitions are given. The temper designations used to identify wrought alloys are explained.

The fabricating procedures, specifications, inspection and uses for (1) sheet and plate, (2) rolled rod, (3) extruded rod, bar and shapes and (4) tubing are presented in some detail.

Aircraft parts ready for protective coatings or assembly are mentioned as being available to the aircraft manufacturer.

Methods of processing are cited briefly, and the paper concludes with remarks as to general considerations in using aluminium alloys.

The main purpose of this paper is to give the aircraft personnel sufficient knowledge to order intelligently, inspect and work these commodities to the benefit of himself, the supplier and the country.

1372
ECONOMIC ADVANTAGES OF CERTAIN ALUMINIUM ALLOYS FOR AIRCRAFT CONSTRUCTION

(K. F. THORNTON, Inst. Aeron. Sci. 10th Annual Meeting, Jan., 1942, pp. 1-21)

Many aircraft parts, particularly fairings, cowlings, skin covering, etc., are often not intended to carry high stresses. Further, because of the necessity for a certain inherent stiffness or because of handling considerations, it is not always possible to use material as thin as would be permitted by considerations of design stresses alone. With these points in mind it is thought that considerable economic advantage can be gained by the more extensive use of certain lower strength, lower priced and more readily workable materials than the high strength aluminium alloys now generally employed. The aluminium alloys 53S, 61S and A51S possess the desirable characteristics of relative ease of fabrication, inherent resistance to corrosion, adaptability to spot welding and ease of forging when compared with such commonly employed structural alloys as 24S and 14S. Shop procedures may be employed which avoid troublesome distortion of parts as a result of quenching.

28758 **SPOT WELDABILITY OF ALUMINIUM ALLOYS**

(C. L. HIBERT, Aero. Digest, Vol. 31, No. 1, July, 1941, pp. 190-200)

Conditions which are known to affect spot weldability of Al. Alloys are: chemical composition, surface condition, conditions under which welding is performed, type of service to which the product is put and the technical education and experience of the welding personnel. The main difficulty is the high thermal conductivity of Al. Alloys, which however depends to some extent on composition and heat treatment. Soft material is generally more conducting and correspondingly more difficult to weld. Conditions under which welding takes place, such as machine settings, size and shape of electrode, edge distance and accessibility play a large part in the success or failure of the operation. The author discusses some of these points in detail and describes modern form of equipment designed to rule out the personal element as much as possible. Of all the factors, the human element is the most difficult to control. Each operator has his own method and at least six months are required to train him to the point where consistent work can be expected. Quality, rather than speed, is to be aimed at.

At present most of the spot welding is restricted to secondary structures. A proper weld is however as strong as the riveted job. The difficulty is to ensure consistency in large-scale production and devise a method of non-destructive testing.

28763

STRENGTHENING ALUMINIUM FOR AIRCRAFT STRUCTURES

(K. R. JACKMAN, Metal Progress, Vol. 40, No. 1, July, 1941, pp. 35-42, 88)

A typical modern four-engined aircraft weighing 50,000 lbs. gross will have a tare weight of about 27,000 lbs. of which 11,000 lbs. represent engines, propeller, accessories and non-structural furnishing. The remaining 16,000 lbs. of structure will be subdivided roughly as follows :

Metal	Form	Wing	Fuselage	Tail	Landing gear	Controls and Misc.	Total
Steel ..	Cr-Mo	300	200	20	1,000	80	1,600
	Stainless	500	50	—	—	50	600
Magnesium	Castings	—	—	—	—	50	50
Al. Alloy	Sheet	7,000	2,100	800	100	500	10,500
	Extrusion	150	100	50	25	75	500
	Drawn Parts	950	400	100	—	50	1,500
	Castings	—	—	—	—	100	100
	Forgings	150	50	25	100	25	350
	Rivets	250	100	50	—	50	450
Others ..	all	20	20	20	40	100	200
						Grand total	15,850 lbs.

Aluminium alloys thus account for 13,400 lbs. out of the total of 15,850 lbs. The sheet metal covering wings, fuselage and tail represents the biggest item, i.e., 10,500 lbs. The present trend is to use 24 ST Alclad sheet which eliminates most of the corrosion troubles, and very little can be done to strengthen this product still further so as to save weight.

It has been known however for some time that extrusions and drawn shapes can be considerably strengthened by cold working and although the total weight of products of this type in the aircraft under consideration amount to only 2,000 lbs., this treatment would be worth while provided practical shop procedures can be developed. The author describes the method adopted by Consolidated Aircraft for prestretching structured sections to 3½% permanent set on the straightening jig at very little extra cost. The gain in ultimate and yield strength of the material is such that a saving in weight of about 10% results. The reason for limiting the prestretching to 3½% permanent set is mainly the need for retaining sufficient residual elongation to accommodate stress concentrations and dynamic load. Greater prestretching also increases the amount of rejected material.

25280 SPOT WELDING OF ALUMINIUM FOR AIRCRAFT

(L. P. WOOD, Metal Progress, Vol. 38, No. 3, Sept., 1940, pp. 274 and 334)

Whilst the cost of driving an average aircraft rivet varies between 1.5 and 3.5 cent, the corresponding spot weld only costs about .25 cent. The saving in time and money by spot welding is thus considerable. Nevertheless the practice does not appear to have been adopted extensively in the U.S.A. except for certain semi-structural parts In Europe, on the other hand, the use of spot welding has been much more general and it is stated that military aircraft now in action have a considerable amount of spot welds, many in vitally stressed parts. One of the most successful welding machines for this purpose is the French Sciaky Welder which embodies two new features : the use of D.C. current and a variable contact pressure cycle at the weld. The direct current is obtained in the following manner. The normal 3-phase shop circuit is converted by means of a mercury arc rectifier into a series of unidirectional impulses which pass through the primary of a choke transformer. When the field strength has reached a certain amount, the primary circuit is cut automatically and a transient D.C. current of high amperage is generated in a secondary winding connected to the welding circuit. The contact pressure device subjects the area to be welded to a high preliminary pressure. Immediately before the passage of current this pressure is reduced but applied again to the full amount when the transient current has diminished to about half its maximum value. The pressure is held whilst the metal is still hot and improves the grain structure of the weld.

The process has the further advantage that the preliminary cleaning of the surfaces can be dispensed with in certain cases.

29098

AVOIDING GALVANIC CORROSION IN LIGHT ALLOY PRODUCTS

(TAYLOR, Metallurgia, June, 1941, pp. 43-46 and 66)

It is stated that many failures of metals and alloys in service are due to galvanic corrosion, and in this article means by which this form of corrosion proceeds are discussed. Some considerations in the design of composite components are given with the object of avoiding or reducing galvanic action and some principles are discussed, the observance of which is claimed to limit the number of failures from this cause.

(*Abstract supplied by Research Dept., Met. Vick.*)

R.T.P. Ref.	*Title and Journal*
25929 U.S.A.	*Welding of Aluminium.* (G. O. Hogland, Metal Progress, Vol. 38, No. 4, Oct., 1940, p. 483.)
25936 U.S.A.	*Aluminium Aircraft Forgings.* (L. W. Davis, Metal Progress, Vol. 38, No. 4, Oct., 1940, pp. 515-6.)
25937 U.S.A.	*Aluminium and its Alloys.* (T. W. Bossert, Metal Progress, Vol. 38, No. 4, Oct., 1940, p. 535.)
26092 Gt. Britain	*Production of Aircraft Components in Alclad.* (P. S. Houghton, Light Metals, Vol. 3, No. 34, Nov., 1940, pp. 278-80.)
26434 Gt. Britain	*Soldering of Aluminium and its Alloys.* (Light Metals, Vol. 4, No. 38, March, 1941, pp. 64-6.)
29087 U.S.A.	*Controlled Al. Bronze for Aircraft Parts.* (G. R. Drehler, Metal Progress, Vol. 38, No. 6, Dec., 1940, pp. 789-796.)

MAGNESIUM AND ALLOYS

25654 Gt. Britain	*Protection of Magnesium Alloys.* (Airc. Prod., Vol. 11, No. 12, Dec. 1940, pp. 408-411.)
25938 U.S.A.	*Magnesium and its Alloys.* (L. B. Grant, Metal Progress, Vol. 38, No. 4, Oct., 1940, pp. 535-7.)
25954 Gt. Britain	*Magnesium in Aircraft Construction.* (Airc. Prod., Vol. 3, No. 27, Jan., 1941, pp. 17-18.)
29619 U.S.A.	*Mg. Alloys in the Aircraft Industry* (*from the U.S.A.*). (J. C. Mathes, Airc. Eng., Vol. 13, No. 153, Nov., 1941, pp. 323-324 and 326.)
142 Gt. Britain	*R.A.E. Anti-Corrosion Treatment for Elektron A.Z.* 91 *Alloy.* (Metal Industry, Vol. 60, No. 1, 2nd Jan., 1942., p. 5.)
1726 Gt. Britain	*The Alloys of Magnesium.* (F. A. Fox, Metal Industry, Vol. 60, No. 14, 3rd April, 1942, pp. 239-241.)
1860 Gt. Britain	*Alloys of Magnesium.* (F. A. Fox, Metal Industry, Vol. 60, No. 15, 10th April, 1942, pp. 260-262.)
2704 Gt. Britain	*Atmosphere Control in the Heat-Treatment of Magnesium Products.* (C E. Nelson, Metal Industry, Vol. 60, No. 21, 22nd May, 1942, pp. 355-56.)
2857 Gt. Britain	*Electrolytic Magnesium.* (Light Metals, Vol. 4, No. 52, May, 1942 p. 170.)
2908 Gt. Britain	*Magnesium Castings.* (Aircraft Production, Vol. 4, No. 40, February, 1942, pp. 210-211.)

25901

MAGNESIUM ALLOYS IN AIRCRAFT. DETAILS OF AMERICAN PRACTICE

(N. E. Woldman, Metal Industry, Vol. 57, No. 24, 13th Dec., 1940, pp. 465-8)

Magnesium alloys can be produced in the following forms:—(i) Castings: sand cast, permanent mould and die cast. (ii) Forgings: hammer and press forgings. (iii) Wrought: extrusions, sheets, plates and bars. The constitution and physical properties of the casting, forging and wrought alloys are discussed. Not all of them are susceptible to heat treatment. The last-named, which is a solution treatment with or without an ageing treatment, produces the optimum physical properties. The solution treatment consists in heating the parts to 650-720° F. for a sufficient time (16-20 hours) until the insoluble constituents go into solution and then air cooling. This treatment increases the strength and ductility to maximum toughness. When followed by ageing for 12 16 hours at 340-400, the tensile strength and hardness are further increased with a sacrifice in ductility. Magnesium alloys, while possessing good tensile and fatigue properties, are very notch-sensitive. Hence notches, scratches, sharp corners must be avoided, also cavities, in which moisture can accumulate and cause corrosion. Electrolytic corrosion in contact with brass and steel is prevented by plating with cadmium. Mg.-alloys can safely be used at low temperatures but are not recommended for resistance to wear. Salt water corrosion is prevented by an anti-corrosive treatment known as chrome pickle ($Na_2CrO_4 + HNO_2 +$ water). This produces a yellow porous coating of chromates which has definite anti-corrosive properties, and at the same time provides a good base for painting.

27251

MAGNESIUM IN AIRCRAFT

(Inter Avia, No. 759, 9th April, 1941, pp. 8-9)

In order to improve the aerodynamic refinement of an aeroplane, very smooth surfaces are required, and great demands are placed on the buckling strength of the aircraft skin, for example in dives. By means of flush-riveting, spot-welding and other methods, satisfactorily smooth surfaces can be obtained; however, the strength of thin-gauge skins is not sufficient to maintain the surface smoothness also under great loads, as a result of which increasingly heavy skins will be required in monocoque construction. Furthermore, the loads placed on the skin by the local formation of compressibility shock, resulting from the velocity of sound being exceeded locally can grow to such an extent that heavier sheet than heretofore must be employed. According to the Dow Chemical Company (Spring Session of the Society of Automotive Engineers), magnesium alloys are quite suitable for use as skin material in view of their low specific gravity.

NEW MAGNESIUM ALLOY

1042 (Metal Industry, Vol. 60, No. 8, 20th Feb., 1942, p. 147)

The addition of 6% silver to Dowmetal "X" (3% Al., 3% Zn., 0.2% Mn.) produced the strongest magnesium alloy yet found. In extrusions it is heat-treatable to a tensile strength of 55,000 lbs. per inch^2, a yield of 45,000 lbs per inch^2 and an elongation of 7%, which approaches the properties of the commonly used 24S-T aluminium alloy extrusion (60,000, 44,000, 12% respectively) which, however, weighs 50% more.

This alloy is not yet adaptable to sheet. The best material so far produced which is workable, is considerably weaker than Alclad 24S-T sheet, but the thicker sheet which will have to be used for aircraft skins would have the advantage of greater stiffness under compressive and shear loads. The 6% of silver in the alloy would about double the cost of magnesium alloy in ingot form. It would, however, provide an outlet for some of the 200 million ounces of silver produced yearly in the Americas, of which two-thirds has no use at present.

If a 6% silver alloy saves weight in aircraft, it will doubtless be worth the cost, as it has been calculated for civil aircraft on the basis of a five-year life and eight hours' daily flying that the income per lb. of dead load comes out to be about $35 per ounce, so that weight saving is literally worth its weight in gold. This, also, incidentally points out the need for close tolerances on aircraft sheet.

1858 **MAGNESIUM FIRES**

(Metal Industry, Vol. 60, No. 15, 10th April, 1942, p. 158)

According to a U.S. Bureau of Mines report, a new and more effective method of extinguishing magnesium fires in commercial plants has been developed by the Bureau. Whilst designed for places where magnesium is being handled continuously, the method is said to be equally effective against incendiary bombs in war-time. Hard coal-tar pitch in granulated or flaked form is said to be a highly satisfactory substance for extinguishing a magnesium flame as the pitch softens and forms an air-tight blanket which quickly smothers the flame. This method is regarded as superior to the use of sand and water, or prepared compounds such as carbon tetrachloride, carbon dioxide and foam. Powdered pitch should not be used, as it has explosive characteristics similar to those in coal and other dusts. Further advantage claimed for pitch for use in industrial plants is that it is not abrasive and not likely to damage costly machinery.

R.T.P. Ref.	*Title and Journal*
	COPPER
28306 Gt. Britain	*Beryllium Copper in the Aircraft Industry.* (Airc. Eng., Vol. 13, No. 150, Aug., 1941, pp. 230-236.)
29154 Gt. Britain	*Fabricating Fittings by Bronze Welding.* (E. Christie, Aircraft Eng., Vol. 13, No. 152, Oct., 1941, pp. 295-296.)
707 Gt. Britain	*Beryllium Copper Alloys.* (Metal Industry, Vol. 59, No. 19, 7th Nov., 1941, p. 296.)
	NICKEL
25928 U.S.A.	*Nickel, Inconel, Monel.* (H. E. Searle, Metal Progress, Vol. 38, No. 4, Oct., 1940, pp. 466-7.)
751 Gt. Britain	*Methods of Joining Monel, Nickel and Inconel.* (Metal Industry, Vol. 59, No. 12, 19th Sept., 1941, p. 184.)
2289 Gt. Britain	*Properties of Monel Metal at Low Temperatures.* (Engineering, Vol. 153, No. 3980, 24th April, 1942, p. 340.)
2874 Gt. Britain	*Spot-Welding Nickel Alloys.* (Autom. Eng., Vol. 32, No. 424, June, 1942, p. 246.)
	PLASTICS
25600 Gt. Britain	*Aircraft Developments in Plastics.* (Plastics, Vol. 4, No. 40, Sept, 1940, pp. 248-250.)
25663 U.S.A.	*Trimming Tabs made of Plastic Material.* (Autom. Ind., Vol. 34, No. 21, 15th Oct., 1940, pp. 434-5.)
25946 Gt. Britain	*Plastic Wings over the Empire (Editorial discussing the Vidal Process).* (Plastics, Vol. 5, No. 44, Jan., 1941, pp. 1-2.)
25947 Gt. Britain	*Adhesives and Cements (based on Synthetic Resins).* (E. E. Halls, Plastics Vol. 5, No. 44, Jan., 1941, pp. 5-8.)
26243 U.S.A.	*Laminated Plastics for Aircraft Parts.* (S. W. Place, Aero. Digest, Vol. 38, No. 1, Jan., 1941, pp. 122-31.)
26272 U.S.A.	*Development of a Plastic Moulded Aeroplane.* (H. P. Moon, Aviation, Vol. 40, No. 1, Jan., 1941, pp. 44-5, 140 and 144.)
26297 U.S.A.	*Plastics used in the Fabrication of Larger Parts of Aircraft.* (H. Chase, Autom. Ind., Vol. 84, No. 2, 15th Jan., 1941, pp. 63-7, 100.)
26363 Gt. Britain	*Synthetic Rubber and Plastics.* (H. Baron, British Plastics, Vol. 12, No. 141, Feb., 1941, pp. 276-8.)

R.T.P. Ref.	Title and Journal
	Plastics—*continued*
26364 Gt. Britain	*Low-Temperature Resistant Plastics for Safety Glass.* (British Plastics, Vol. 12, No. 141, Feb., 1941, p. 285.)
26804 U.S.A.	*Plastic Tabs for Ailerons, Rudder or Elevator.* (Sci. Am., Vol. 164, No. 1, Jan., 1941, pp. 160-61.)
26580 Gt. Britain	*Plastics in Industry (Book Review).* (Plastics, Chapman & Hall, 1940. (Engineer, Vol. 171, No. 4446, 28th March, 1941, p. 212.)
27449 Gt. Britain	*Plastic Components for Aircraft.* (Airc. Prod., Vol. 111, No. 32, June, 1941, p. 192.)
27738 U.S.A.	*Plastics in Aircraft.* (J. E. Simonds, Aviation, Vol. 40, No. 5, May, 1941, pp. 38, 124 and 128.)
27740 U.S.A.	*Moulding Plastics in Aircraft.* (R. Decat, Aviation, Vol. 40, No. 5, May, 1941, pp. 41, 126 and 128.)
28317 Gt. Britain	*Screw Threads in Plastics.* (Plastics, Vol. 5, No. 51, Aug., 1941, pp. 163-164.)
28510 Canada	*Plastic Aeroplanes Built in Canada (Vidal, Timm and Duramold Processes).* (Inter. Avia., No. 772-73, 15th July, 1941, p. 16.)
28620 Gt. Britain	*Incorporation of Metal Powders in Plastics.* (H. W. Greenwood, Plastics, Vol. 5, No. 52, Sept., 1941, pp. 167-168.)
28847	*Plastic Bearings in Service.* (Plastics, Vol. 5, No. 53, Oct., 1941, pp. 205-208.)
28982 Gt. Britain	*Synthetic Resins in Aeroplane Construction.* (H. N. Haut, British Plastics, Vol. 13, No. 146, July, 1941, pp. 54-58.)
29358 U.S.A.	*Plastics in Aircraft Construction.* (W. H. Francis, Aero. Digest, Vol. 38, No. 3, March, 1941, pp. 238-240 and 272.)
29460 Gt. Britain	*"Ardux" Cement for Bakelite Materials.* (Flight, Vol. 40, No. 1715, 6th Nov., 1941, p. 316.)
29461 Gt. Britain	*"Aerolite F67" Foamed Formaldehyde Glue.* (Flight, Vol. 40, No. 1715, 6th Nov., 1941, p. 316.)
29500 Gt. Britain	*Plastic and Powder Metallurgy (Incorporation of Metal Powders).* (H. W. Greenwood, Plastics, Vol. 5, No. 54, Nov., 1941, pp. 215-216.)
29657 U.S.A.	*Plastic Bonding in Aeroplane Construction (Bellanca Aircraft).* (Ind. and Eng. Chem. (News Ed.), Vol. 19, No. 20, 25th Oct., 1941, p. 1154.)
29849 U.S.A.	*Plastic Gliders.* (American Aviation, Vol. 5, No. 11, Nov., 1941, p. 6.)
29724 U.S.A.	*Plastics Applied to Aeroplane Structure.* (C F. Marschener, Mech. Eng., Vol. 63, No. 11, Nov., 1941, pp. 787-790.)
29748 Gt. Britain	*Synthetic Rubber and Plastics.* (H. Barron, British Plastics, Vol. 13, No. 150, Nov., 1941, pp. 176-179.)
29770 Gt. Britain	*Plastic Insulating Sleeving.* (W. Cornelius, Plastics, Vol. 5, No. 55, Dec., 1941, pp. 236-237.)
29771 Gt. Britain	*Coating Plastics with Metal.* (Plastics, Vol. 5, No. 55, Dec., 1941, pp. 240-241.)

R.T.P. Ref.	Plastics—*continued*
217 U.S.A.	*Langley "Plastic" Plane (Bonded Plywood).* (Flight, Vol. 41, No. 1724, 8th Jan., 1942, p.h.)
203 Gt. Britain	*Aircraft Plastic Components.* (Airc. Prod., Vol. 4, No. 39, Jan., 1942, p. 126.)
644 U.S.A.	*The "Langley" Plastic Plane.* (R. Hawthorne, Aviation, Vol. 40, No. 11, Nov., 1941, pp. 72-73, 162-168.)
869 U.S.A.	*Plastic Hammers for Aircraft Manufacturing.* (Aero. Digest, Vol. 39, No. 6, Dec., 1941, p. 251.)
786 Gr. Britain	*The Future of Plastics in Aircraft.* (Plastics, Vol., 5 No. 57, Feb., 1942, pp. 1-2.)
787 Gt. Britain	*Synthetic Rubber.* (Plastics, Vol. 5, No. 57, Feb., 1942, pp. 3-4.)
1536 Gt. Britain	*Engineering Possibilities of Plastics.* (Metal Industry, Vol. 60, No. 10, 6th March, 1940, p. 176.)
1750 Gt. Britain	*Synthetic Rubber.* (O. M. Hayden, Engineer, Vol. 173, No. 4499, 3rd April, 1942, pp. 285-287.)
1936 Gt. Britain	*Plastics (a New Material of Construction).* (C. Chapman, Engineer, Vol. 173, No. 4502, 24th April, 1942, pp. 353-355.)
2002 Gt. Britain	*Plastics in Aircraft.* (J. D. North, Plastics, Vol. 6, No. 59, April, 1942, pp. 85-86.)
2003 Gt. Britain	*Plastic Tape for Identification Purposes.* (Plastics, Vol. 6, No. 59, April, 1942, pp. 87-89.)
2004 Gt. Britain	*Metal Protection by Plastic Sheet and Film.* (E. E. Halls, Plastics, Vol. 6, No. 59, April, 1942, pp. 101-107.)
2347 U.S.A.	*Use of Plastics in American Aircraft.* (British Plastics, Vol. 13, No. 153, Feb., 1942, pp. 307-309.)
2349 Gt. Britain	*Synthetic Rubber and Plastics, IX.* (H. Barron, British Plastics, Vol. 13, No. 153, Feb., 1942, pp. 345-350.)
2742 Gt. Britain	*Metal Protection by Plastic Sheet and Film.* (E. E. Halls, Plastics, Vol. 6, No. 60, May, 1942, pp. 141-147.)
2910 Gt. Britain	*Gliders to Utilise Plastics.* (Airc. Prod., Vol. 4, No. 40, Feb., 1942, p. 211.)
2747 Gt. Britain	*Plastics versus Leather.* (Haydon K. Wood, Plastics, Vol. 6, No. 61, June, 1942, pp. 164-165.)
2748 Gt. Britain	*Lignin—a Plastic from Wood.* (J. Grant, Plastics, Vol. 6, No. 61, June, 1942, pp. 166-171.)
2751 Gt. Britain	*Plastics Cutting Tools (Prod.).* (Plastics, Vol. 6, No. 61, June, 1942, p. 191.)
2879 Gt. Britain	*New Methods for Mechanical Testing of Plastics.* (L. H. Callender, British Plastics, Vol. 13, No. 155, April, 1942, pp. 445-458.)
2883 Gt. Britain	*"Preformed" Plastics.* (British Plastics, Vol. 13, No. 155, April, 1942, p. 468.)

R.T.P. Ref.	
3011 U.S.A.	*Synthetic Resin in Construction (Pt. 1).* (H. N. Haut, Aviation, Vol. 41, No. 3, March, 1942, pp. 84-85.)
3098 U.S.A.	*Tubing of Transparent Plastics.* (Ind. and Eng. Chem. News Edition, Vol. 20, No. 9, p. 632, 10th May, 1942.)
3164 Germany	*New German Plastic Bearing.* (Airc. Prod., Vol. 4, No. 43, p. 331, May, 1942.)
3427 U.S.A.	*S.A.E.-A.S.T.M. Specifications for Synthetic Rubber.* (S.A.E.J., Vol. 50, No. 6, June, 1942, pp. 20-22.)
3442 Gt. Britain	*Use of Plastic in Crash-Resistant Fuel Tanks.* (J. W. Baird, British Plastics, Vol. 13, No. 157, June, 1942, p. 22.)
3445 Gt. Britain	*Cellulose.* (British Plastics, Vol. 13, No. 157, June, 1942, pp. 48-50 and 53.)
3522 Gt. Britain	*Plastics in Armament and Aircraft.* (Plastics, Vol. 6, No. 62, July, 1942, p. 219.)
3523 Gt. Britain	*Du Pont Plastics (Pyralin, Plastacele, Cell-o-glas (Transmits Ultra Violet), Lucite, Nylon (Brushes), Butaxite (Laminated Glass), Reoprene).* (Plastics, Vol. 6, No. 62, July, 1942, pp. 222-224.)
3635 Gt. Britain	*Spitfire Pilot Seat Made of Plastics.* (Z.V.D.I., Vol. 86, No. 25-26, 27th June, 1942, p. 398.)

28518

SYNTHETIC RESINS AS AIRCRAFT CONSTRUCTION MATERIALS

(Inter. Avia., No. 774, 23rd July, 1941, pp. 1-5)

(1) Properly selected synthetic resins have the following properties which make them suitable for the aircraft industry: Good mouldability, low specific weight, smooth surface, low inflammability, resistance to chemicals and bacterial growths, low hygroscopicity, great energy absorption for oscillation damping, manufacture from non-strategic raw materials.

(2) Synthetic materials suitable for the manufacture of entire airframes without stiffening additions not known at present.

(3) The strengthening of synthetic resins to the values required for the manufacture of aircraft by means of fabric fillers is not excluded; however, materials of this class ready for use are not yet available.

(4) Wood improved by means of synthetic resins and plastics strengthened by means of wood layers are widely and advantageously adopted to-day.

(5) Methods and installations for the industrial manufacture of airframe components from compound wood/plastics materials are available.

(6) The "plastics aircraft" available to-day are made exclusively of wood improved by synthetic resins on the principles of conventional plywood construction under the application of the processes in question for the manufacture of shell components.

(7) The development of a method for the construction of wood/plastics aircraft in which the properties of the new compound materials are fully exploited with a view to reducing the manufacturing time, the quantity of material needed and the weight, and to adapting them to the static and aerodynamic requirements, is still in its infancy.

5523 PLASTICS FOR AIRCRAFT CONSTRUCTION

(H. STENER, Flugsport, Vol. 34, No. 21, 14th Oct., 1942, pp. 315-320)

Of the two main classes of plastics, viz., thermoplastic and thermosetting, the latter are of principal interest to the aircraft constructor on account of their better mechanical properties.

In German literature, thermosetting plastics are known as synthetic resins (Kunstharze) and the author describes the principal methods of moulding such products under pressure. After manufacture, the parent plastic is in the so-called state A and contains

a considerable amount of moisture, some of which is next driven off, the powdered product then being in the so-called sensitive state B. This moulding powder is mixed with a filler (usually wood flour) and sprinkled into a metal die kept at about 160° C. The pressure applied and time of contact depend on the shape and size of the required article and vary from 150 to 1,200 atmosphere and 1 to 6 minutes.

Under these conditions, the resin powder first melts and then resolidifies (irreversible change), passing into the final hard C state.

If the finished article has to be machined out of the solid (plate or rod) it is advisable to use a plastic containing a fabric filler. The fabric (linen or flax) is first impregnated with resin in state " A " dissolved in alcohol. Subsequent heating and drying (atmospheric pressure) converts the resin into the sensitive state B.

5377 PLASTICS IN ENGINEERING

(J. Prior, Engineering, Vol. 154, No. 4006, 23rd Oct., 1942, pp. 324-325)

Moulded plastics are of two principal types—thermosetting and thermoplastic. The former undergo an irreversible chemical change during the hot moulding process, yielding a hard product which cannot subsequently be softened. Thermoplastics on the other hand (as is indicated by their name) become soft on being heated and this process is reversible.

The chemical reaction producing thermosetting plastics is usually carried out in two stages—the first at a moderate temperature yielding an intermediate resin by the action of formaldehyde or urea on phenol in the presence of a catalyst. This resin is then mixed with a filler and the chemical reaction completed in the final moulding at a higher temperature.

Thermoplastics may be either truly resinous (vinyls, styrenes, etc.) or require the addition of a plasticiser. A filler is however not generally added. The principal properties of representative plastics of both classes are given in the table below. Engineering uses referred to by the author include: toothed gears, bearings, control lever knots, transparent inspection doors and small moulded parts of highly finished condition not requiring any subsequent machining (tolerance of .001 inch are often adhered to).

The Properties of Plastics

Properties	Thermo-setting			
	Formaldehydes			
	Phenol Moulded	Phenol Laminated	Phenol Cast (No Filler)	Urea Moulded
Average ultimate tensile strength, lb. per sq. in.	11,000	18,000	12,000	12,000
Average ultimate compressive strength, lb. per sq. in.	36,000	40,000	30,000	35,000
Elongation, per cent. ..	—	—	—	—
Specific gravity	1.3	1.38	1.3	1.45
Resistance to continuous heat, deg. F.	350 to 450	212 to 450	160	160
Softening point, deg. F. ..	None	None	—	None
Effect of weak acids ..	None to slight, depending on acid			Decomposed or surface attack.
Effect of strong acids ..	Decomposed by oxidising acids. Reducing and organic acids, no effect.			
Effect of weak alkalis ..	Slight to marked, depending on alkalinity			
Effect of strong alkalis ..	Decomposes	Decomposes	Decomposes	Decomposes
Effect of metal inserts ..	None	None	None	None
Clarity	Opaque	Opaque	Opaque	Transparent to Opaque
Colour possibilities ..	Limited	Limited	Unlimited	Unlimited (pastel shades)
Machining qualities ..	Fair to good	Fair to excellent	Excellent	Fair

Properties	Thermosplastic				
	Vinyl Chloride Plasticised	Styrene Resin	Cellulose Acetate		Casein
			Sheet	Moulded	
Average ultimate tensile strength, l. per. sq. in. ..	Up to 9,000	9,000	9,000	8,000	7,500
Average ultimate compressive strength, lb. per sq. in.	—	13,500	16,000	227,000	—
Elongation, per cent	2 to 500	1.0	20 to 55	8 to 30	—
Specific gravity ..	1.2 to 1.6	1.06	1.32	1.32	1.35
Resistance to continuous heat, ° F.	150		140 to 180	140 to 180	—
Softening point, ° F.		190 to 250	140 to 230	140 to 260	200
Effect of weak acids	None	None	Slight	Slight	Resistant
Effect of strong acids	None	None	Decomposes	Decomposes	Decomposes
Effect of weak alkalis	None	None	Slight	Slight	Softens
Effect of strong alkalis	None	None	Decomposes	Decomposes	Decomposes
Effect of metal inserts	None	None	None	None	None
Clarity	Transparent to opaque	Transparent 90 to 92% light transmission	Transparent translucent or opaque		Translucent opaque
Colour possibilities	Unlimited	Unlimited	Unlimited	Unlimited	Unlimited
Machining qualities	Good	Poor to Good	Good	Good	Good

2884

A NEW INSULATION MATERIAL

(British Plastics, Vol. 13, No. 155, April, 1942, pp. 468)

"Preformed" Plastics. The Westinghouse Research Laboratories, under the direction of Dr. A. A. Bates, manager of the chemical and metallurgical departments, is experimenting with a new "preformed" plastics material expected to combine the strength of laminated plastics with the ductility of the moulded type. The moulded type by itself is said to lack the strength needed for some applications, while laminated plastics have not lent themselves to the formation of complex shapes. The new plastic is produced by forming a mixture of wet pulp and resin in the shape of the finished product, which is then baked under pressure in an oven to harden the resin. This material was first to be used for making parts for household appliances in order to dispense with sheet steel and thick walls of insulating materials. The product is also to be used for Army supplies. A new two-part helmet, lighter than the present helmets, is being worked on. The inner part, made of the preformed plastics, can be worn during ordinary field operations, while a steel outer shell can be added in actual battle.

25197

NEW COVERING FOR THE WING UNIT OF AIRCRAFT

(L'Ala d'Italia, 16th-30th, June, 1940, p. 51)

The German aeronautical experimental centre has patented a new process for the covering of wing surfaces. This covering, which is perfectly water and airtight, consists of a metal fabric between two layers of compressed synthetic resin. For example, using a metal fabric with a weave of 50 to 120 meshes per sq. cm., spun with a 0.12 mm. wire, a covering is obtained with a resistance of 2,000 to 3,000 kg. per metre, for a unit weight of 600 gm. and thickness of not more than 0.5 mm.

1890

VINYLIDENE CHLORIDE POLYMERS "SARAN" UPHOLSTERY FABRICS ETC.

(W. C. GOGGIN and R. D. LOWRY, Ind. and Eng. Chem. (Ind. Ed.), Vol. 34, No. 3, March, 1942, pp. 327-32)

Vinylidene chloride plastic as a new and unusual material is discussed from the standpoint of history, chemical and physical structure, outstanding characteristics, methods of fabrication, and application.

These resins differ from familiar plastic materials in that they exhibit crystallini ty, as can be demonstrated by X-ray diffraction patterns. While presenting some mechanical problems, the control of this crystallinity offers a wide range of properties and unique fabrication techniques. The extrusion and continuous orientation of vinylidene chloride plastic is now a commercial accomplishment. Injection moulding of these resins, along with control of moulding properties, is presented for the first time. Applications are cited illustrating some fabrication methods as well as the unusual characteristics of chemical inertness, water resistance, high strength, toughness, and abrasion resistance. Upholstery fabrics made of this material (trade name "Saran") have already reached extensive application.

28579

A NEW PLASTIC MATERIAL

(Inter. Avia., No. 770-71, 27th June, 1941, p. 17)

A construction material which apparently is particularly suitable for the aircraft industry has been developed under the designation *Fybr-Tech*. It consists of a single layer of wood with a layer of artificial fibre bonded by means of artificial resin to each side. The strength of this very light material is stated to be exceedingly satisfactory. Fybr-Tech can readily be sawed, drilled and stamped, immaterial of the direction of the grain, and can be formed under the application of heat without detrimental effect on the surface. Its resistance to meteorological influences is stated to be very good. The idea of using several laminated materials in the construction of aeroplanes is not new and has been adopted in France some considerable time ago. For example, the well-known "Plymax" skin, consisting of three-ply wood on which aluminium sheet was bonded by means of casein for the absorption of torsional stresses, was extensively used in the construction of the Morane 406 single-seater fighter.

4648

PRESSURE DIE CASTING OF IGAMID PLASTIC

(H. BECK and F. SCHAUPP, Kunststoffe, Vol. 32, No. 7, July, 1942, pp. 205-209)

Linear poly condensation products, for example from diamines and dicarbonic acids (polyamides), are manufactured in the U.S.A. under the name of nylons, and in Germany under the name of Igamid. These plastics have a relatively high melting point and the molten product has very small viscosity. Pressure die casting, especially on mass production lines, thus requires special precautions to prevent leakage loss at the injection nozzle when the die is changed, or solidification of plastic in the nozzle when in contact with the relatively cool die. The author has developed a special needle, controlled injection nozzle which only opens when the die is in position and which is closed automatically by an external spring on withdrawal of the die. The cone-shaped recess of the cup on the die into which the nozzle fits is undercut to reduce cooling losses, and elaborate electric heating devices are incorporated on the body of the valve to prevent plugging. It is stated that the valve has given satisfaction in practice, and the mass production of die castings in this type of plastic has now become possible. Since these polyamides possess most valuable characteristics (great impact strength and deformability) this development in die casting for mass production is thought to have great commercial possibilities.

358

DETERMINATION OF THE HARDNESS OF PLASTIC BY A MODIFIED BRINELL METHOD

(Z.V.D.I., Vol. 84, No. 15, 13th April, 1940, p. 252)

According to German Engineering Specification V.D.E. 0302, the hardness of a plastic is calculated from the depth of impression of a 5 mm. steel ball whilst carrying

a 50 kg. load. Erk and Holgmuller (Kunstoffe, Vol. 28 (1938), pp. 109-113) have pointed out that the total deformation measured under these conditions consists partly of a permanent (plastic) set and an elastic deformation. Since the latter may amount to anything between 45% and 90% of the total, depending on type of plastic, it is obvious that the method cannot be used for a direct comparison of hardness. As is well known, the deformation of a plastic is mainly controlled by the time of application of the load. For this reason, Frohlich (Kunstoffe, Vol. 30 (1940), pp. 103-106) has developed a new hardness tester of the rolling type in which the time of application of the load is controlled. In this instrument a steel ball of 5 mm. diameter is caused to roll on the specimen at speeds varying between 5×10^{-6} and 50 mm. per second, the load being constant and equal to 2 kg. When plotting the fourth power of the track width against the fourth root of the time of application of the load, the resulting curves are almost straight, rendering exterpolation to zero time of application easy. For these very short durations of the load plastic deformation can be neglected and it is found the track width of various plastics are roughly in the order of the respective moduli of elasticity.

This method of plotting also enables conclusions to be drawn on the plastic deformation as a function of time. The author carried out experiments on ten representative plastics for load periods of 1, 10 and 60 seconds respectively.

Under these conditions, pressed synthetic K gave the following values for the rolling hardness (Kg. sec./mm^3)

1 second	9940
10 seconds	9030
60 seconds	8550

It will be noted that the change of hardness with duration of load is relatively slight, i.e., plastic flow under long period loads is small for this type of synthetic substance. Similar results are obtained with the plastic " Astralon " and with ebonite.

Synthetics derived from cellulose acetate or celluloid on the other hand are subject to considerable plastic flow under load. The same applies to the synthetic " Mipolain."

2879

NEW METHODS FOR MECHANICAL TESTING OF PLASTICS

(L. H. CALLENDAR, British Plastics, Vol. 13, No. 155, April, 1942, pp. 445-58)

Impact testing to cross-section has been for a long time a need of engineers in many industries, to enable them to test materials in the state in which they are used, instead of relying on doubtful comparative values from specially made-up test pieces. A practical method is here described for impact tests to cross-section on electrical plastics.

In the past the difficulty in the way of testing to cross-section has been mainly due to the general use of the excess swing pendulum method with Izod support. The errors of this method, namely, the " shearing and tearing " error and the " broken-half " error, are shown by a number of examples to be very large for plastics materials and quite sufficient to invalidate it for comparative brittleness testing of this class of materials.

Comparative brittleness testing to cross-section is shown by numerous results to be bound up with the following :—

(1) The use of the same radius of notch, namely, ½ mm., and the same depth of notch, namely, one-third of the thickness of the test-piece for all tests on pieces of any cross-section.

(2) Charpy anvils adjusted to a distance apart equal to six times the thickness of the particular test-piece under test.

(3) A minimum velocity of impact of 8 feet (244 cms.) per second.

(4) The first definite crack or break must be taken as the end-point of the test.

(5) The use of the guillotine or vertical drop-weight type of machine is also advantageous for this purpose; photographs of a recommended design of machine are given.

Among other matters touched on is the importance of plastic yield temperature and controlled humidity in relation to impact testing.

In the Appendices photographs are given of a new simple machine for plastic yield temperature, and also the interesting theoretical question of the uncertain range is gone into at some length.

87

SHEAR STRENGTH OF MOULDED PLASTIC MATERIALS

(J. DELMONTE, British Plastics, Vol. 13, No. 149, October, 1941, pp. 134-35 and 37)

The punch and die are described in the measurement of shear strength upon moulded plastic parts as a useful tool for a rapid method of evaluating this property by moulders. Test results upon phenolics and ureas which have been cured for different periods of time are described. It is pointed out that differences in shear values of moulded phenolics are augmented by several minutes' immersion in acetone, whereas boiling water may be used to reveal substantial variation in the cure of moulded urea parts and their shear strength. Comparative tests upon a large number ot injection-moulded pieces produced in the same mould are outlined, and a table prepared comparing these materials with respect to shear strength. Injection mouldings of polyvinyl chloride-acetate and polymethyl methacrylate proved to be the highest. Further tests designed to show the utility of the punch and die reveal data on the shear strength of moulded plastics as function of temperatures from 0° to 300° F.

4649

INFLUENCE OF HEAT-TREATMENT ON THE IMPACT STRENGTH PLAIN AND NOTCHED OF PLASTICS WITH PAPER OR FABRIC FILLERS

(C. BRINKMANN, Kunststoffe, Vol. 32, No. 7, July, 1942, pp. 205-209)

V.D.E. specification 0318 lays down that plastic with paper or fabric fillers should not be exposed continuously to temperature above 110° C., but that short times exposed to 150° C. are permissible. The author carried out tests on the impact strength of such materials at room temperature after exposure to temperature between 110° and 170° C. for periods up to 800 hours. Two quantities of so called " hard paper " (i.e., plastic with paper filler) made by three different manufacturers were tested as well as one sample of " hard fabric " (fabric filler). The results confirm that such plastics will stand continuous exposure to 110° C., the impact strength (both plain and notched), after undergoing a relatively small drop over the first 50–100 hours, remaining practically constant over the remaining period (800 hours). For the notched specimen the value ranges between 10 and 30 cm. Kg./cm.^{2} for the " hard paper " samples and average about 17 cm. Kg./cm.^{2} for the plastic fabric.

At higher storage temperatures, however, the material undergoes a serious drop in impact strength which continues to diminish with length of storage. Apart from gradual destruction of the filter, loss of moisture and ageing of the plastic (molecular changes) seem to be mainly responsible for the drop in strength.

In must however be emphasised that the tests discussed above only cover impact strength. It is however highly probable that its other mechanical qualities will be affected in a similar manner.

28958

METAL COATING OF PLASTICS

(B.1 Plastics and Moulded Product, Sept., 1941, p. 106)

It is claimed that in the process of coating plastics with zinc, aluminium, copper or tin, the metal particles join with the synthetic resin particles and therefore strengthen the surface of the moulded article. The process can also be applied to cast resin and to laminated and cellulose products. Results are given of test carried out to compare the electro-magnetic screening properties of the metal film with tinfoil of the same dimensions.

(*Abstract supplied by Research Dept., Met.-Vick.*)

R.T.P. Ref.	*Title and Journal*
	WOOD, PAINT, VARNISH, DOPE, FABRIC, GLUES
25652 Gt. Britain	*Use of Cork in Aircraft.* (Airc. Prod., Vol. 11, No. 12, Dec., 1940, pp. 379-381.)
25868 Gt. Britain	*Development in Wood Technology.* (D. Brownlie, Engineering, Vol. 150, No. 3911, 27th Dec., 1940, pp. 502-503.)
26572 U.S.A.	*Compounding of Plastic Wood.* (R. Decat, Aero. Digest, Vol. 38, No. 2, Feb., 1941, pp. 146-149.)

Wood, Paint, Varnish, Dope, Fabric, Glues—*continued*

R.T.P. Ref.	Title and Journal
27132 Gt. Britain	*Plastic Bonded Plywood Structure for Aircraft.* (Plastics, Vol. 5, No. 48, May, 1941, pp. 94-97.)
27126 Gt. Britain	*Plywood for Aircraft (Preparation of Veneers, Jointing and Bonding).* (Airc. Prod., Vol. 3, No. 31, May, 1941, pp. 167-170.)
27458 Gt. Britain	*Aircraft Plywood.* (T. D. Perry, Aircraft Production, Vol. 111, No. 32, June, 1941, pp. 221-223.)
27854 U.S.A.	*Aircraft Structure Laminated with Plastics.* (H. Chase, Autom. Ind., Vol. 84, No. 10, 15th May, 1941, pp. 512-514 and 515.)
29058 U.S.A.	*Fybr-Tech., a New Material for Aircraft Construction (Special Plywood, Veneer Core with Vulcanised Fibre Resin Bonded on Each Face).* (J. R. Fitzpatrick, Aero. Digest, Vol. 38, No. 5, May, 1941, p. 218.)
29221 Gt. Britain	*Synthetic Adhesives for Plywood Manufacture.* (Engineer, Vol. 172, No. 4476, 24th October, 1941, p. 282.)
29501 Gt. Britain	*Foamed Synthetic Glue.* (Plastics, Vol. 5, No. 54, Nov., 1941, pp. 216-217.)
29749 Gt. Britain	*Synthetic Adhesives for Plywood Manufacture.* (British Plastics, Vol. 13, No. 150, Nov., 1941, p. 186.)
29782 U.S.A.	*Testing Wood for Aircraft Construction.* (E. T. Clarke and S. A. Korff, J. Frank. Inst., Vol. 232, No. 4, Oct., 1941, p. 356.)
29855 U.S.A.	*Latest Development in Plywood for Aircraft.* (American Aviation, Vol. 5, No. 12, 15th Nov., 1941, pp. 18-19 and 27.)
2478 U.S.A.	*Wood Plastic Aeroplane Parts.* (C. L. Bates, Aviation, Vol. 41, No. 1, Jan., 1942, pp. 82-83 and 182.)
2918 Gt. Britain	*Laminated Wood (Pat. No. 533, 369).* (Airc. Prod., Vol. 4, No. 40, Feb., 1942, p. 218.)
3162 Gt. Britain	*Resin-Bonded Plywood for Aircraft Construction.* (Airc. Prod., Vol. 4, No. 42, pp. 312-315, April, 1942.)

5604

HIGH DENSITY PLYWOOD

(M. Finlayson, A.S.M.E., October Meeting, 1942, Preprint, pp. 1-21)

This saving is of great value not only because of overall weight reduction, but also because of the decreased inertia of the blade. This weight saving is possible because metal blades for engines of high horse-power require a high percentage of steel and large hubs to absorb the high stresses, both causing large weight increases. Conversely, on engines of low horse-power, low steel content alloys and small hubs can be used and high-density plywood shows very little or no weight advantage.

In addition to the weight saving, the high-density plywood shows a superior resistance to the effect of notches and dents and is more easily repairable. It is reported, on the basis of considerable combat experience, that repairability of high-density plywood blades is 80% as compared with 60% for metal blades. The fatigue resistance of high-density plywood is excellent and its energy absorption much greater than that of metal.

Outside the aircraft field, one application has been developed and is now in use. This is the flare base for the M.26 parachute flare. This piece was formerly produced from die cast aluminium, and is required to take the full shock, across a very small area, of the sudden stress occasioned by the parachute stopping the rapid descent of the heavy flare. High-density plywood withstands this stress very satisfactorily and has proved successful in this application, releasing many thousands of pounds of aluminium for vital aircraft parts.

The physical properties of high-density plywood produced from Tego-bonded birch veneer, the grain direction of all plies parallel, are presented and compared

with the corresponding properties of various metals. It is shown that the strength properties are directly related to the specific gravity. Stress-strain curves in tension indicate that this material not only has no normal yield point but actually shows a decrease in elongation per unit load at high loads. The moduli of elasticity in tension and compression are shown to be greatly different. The behaviour in torsion is discussed, and the effect on the tensile strength of cross laying the veneers is presented. The effect of immersion in water and the effect of various humidity conditions are given.

The greatest progress on the utilisation of high-density plywood has been made by the English in their development of this material for aircraft propellers, one of the most highly stressed units in an aircraft. In England several types of high-density plywood are in use on fighter and fighter-bomber planes. It is claimed that, for example, propellers for high horse-power engines, high-density plywood is much superior to metal. Some of this superiority is due to the ability to get much lighter propellers which satisfactorily withstand the conditions of use. As an example, it is reported that a three-bladed propeller for a 1,750 h.p. engine weighs 300 lbs. less in high-density plywood than in metal.

26916 . AIRCRAFT PLYWOOD AND ADHESIVES

(T. D. Perry, J. Aero. Sci., Vol. 8, No. 5, March, 1941, pp. 204-216

At the period of the 1914 War, either casein (made from the curds of soured milk) or albumen (a dried blood product coagulated under heat) were considered the most durable adhesives for aircraft construction. Neither of these products resisted moulds or fungi. Casein is not very resistant to water. Albumen is better in this respect, but deteriorates seriously with age. After 1930, adhesives made of synthetic resins revolutionised the plywood industry. (Phenol and urea form aldehydes.) These new compounds are characterised by good water resistance, they are not attacked by mould and fungi and are much less damaging to edge tools than the caseins (adhesives). Recently so-called " plastic " aircraft has received much publicity. These planes are made of moulded plywood, the only novel feature being the method of applying the pressure as well as the unusually large size of the moulded unit. The fundamental principle involved is that of using an inflated or deflated rubber bag as one of the halves of a pair of moulding dies. Typical examples of such dies are illustrated. The conventional method of manufacturing aircraft plywood with synthetic resin adhesives has been the use of the steam-heated plater in a hydraulic press. Recently, for thick sections, heating by means of high-frequency electrostatic fields has been successfully carried out.

The author gives some details of wood and plywood construction (spars, ribs, gussets, skin covering, high-density reinforced plates, propellers and bending). Useful tables of the weight, tensile, and bearing strength of a number of representative plywoods are given (including high density woods).

A bibliography of fifty-eight items concludes the paper.

2161
RESIN BONDED WOOD LAMINATES FOR SHELL TYPE AIRCRAFT STRUCTURES

(A. A. Gassner, J. Airon. Sci., Vol. 9, No. 5, March, 1942, pp. 161-171)

Wood as lumber is not homogeneous and it is not isotropic ; it is also more sensitive to atmospheric influences than are the metals. Wood veneers plus synthetic resin as bonding medium will react more nearly like a homogeneous material, and, by suitable design and by consideration of the applied stresses, a construction can be built that will be fully able to carry the required loads, even though the material is not fully isotropic.

Surface coating with synthetic resin finishes makes these structures highly impervious to atmospheric influences and resin impregnation of the basic veneers can be used to make the laminations practically immune against moisture.

These wood-base laminations are exceedingly well suited for the construction of full-stressed shells for aircraft parts with very few internal stiffeners.

In Duramold design, many very thin veneers are used to obtain the highest possible homogeneity at reasonable cost. While commercial plywood of ¼ inch thickness is, for instance, built up from five plies, the Duramold construction would use for the same thickness ten to twelve plies. Commercial plywood is difficult to bend even on large radii, and the bending or forming of commercial plywood to pronounced compound curvature is impractical. Duramold can be moulded to small single radii and it can

be readily moulded to very pronounced compound curved shapes, because each of the very thin veneers is formed separately which requires only small pressures and which introduces hardly any stresses into the single veneer. Then the veneers are formed in the mould to the desired shape, while the layers are bonded together at the same time by the resin.

By use of the stress analysis methods described by the author and based on a long series of tests and investigations, a number of aircraft structures have been designed, constructed and tested.

One of these designs is the stabiliser for the Fairchild M-62 low-wing training plane. This stabiliser is a stressed-skin type without longitudinal stringers and without a front spar. It consists merely of moulded top and bottom shells, whose thickness tapers from approximately $\frac{1}{4}$ inch at the centreline of the aeroplane to $\frac{1}{32}$ inch at the stabiliser tip, of a light rear spar that takes vertical shear and is used for the attachment of elevator and fuselage fittings, of a leading-edge-former that curves in one part into the tip bows, and of a few chordwise ribs. The shell is, on account of its thickness, a very stiff one and assures the maintenance of the proper airofoil section under all conditions of flight loads. In combination with the remainder of the structure it assures very high torsional stiffness, and load tests have shown that the torsional twist of this stabiliser was only .50° under full design load, consisting of the pertaining stabiliser-down and elevator-up loads. The complete weight of this Duramold stabiliser is the same as of the plywood-plus-spars type of the original design.

1018

NEW METHOD FOR MAKING GLUED REPAIRS ON PLYWOOD WING COVERING FOR AIRCRAFT (USE OF NEEDLE CLAMP)

(Luftwissen, Vol. 8, No. 12, Dec., 1941, p. 374)

When carrying out repairs on plywood wing covering, the difficulty arises of clamping the plywood patch tightly over the hole whilst the glue is drying. A special tool is described for this purpose. A long needle carrying a thread through a hole near its point is pushed through the patch and underlying cover. On rotating the tool, the thread winds round the needle and acts as a lock nut preventing its withdrawal. By turning a nut on the upper part of the needle shaft, pressure can then be exerted against a slotted collar and the patch pressed tightly against the base whilst the glue dries.

Withdrawal of the needle is effected by unwinding the thread. The holes made by the needle are only 1.2 mm. diameter and can be easily stopped with varnish to prevent moisture leaking in.

188

THE PLANOFLEX, A SIMPLE DEVICE FOR EVALUATING THE PLIABILITY OF FABRICS

(E. C. Dreby, J. Nat. Bur. Stands, Vol. 27, No. 5, Nov., 1941, pp. 469-77)

The Planoflex, a simple device for measuring the extent to which a fabric can be distorted in its own plane without producing wrinkles on its surface, was developed to evaluate the pliability of woven fabrics. Results of measurements on a series of cotton percales show an 88% correlation with their tactual pliability ratings. Comparison of the Planoflex with the Schiefer Flexometer and the Peirce Hanging-Heart Loop methods for evaluating pliability showed it to be as good as or better than these instruments with respect to the extent of the correlation between measured values and tactual pliability ratings, sensitivity to small differences in pliability, and ease of operation. The Planoflex may be used for testing all woven fabrics except those that are heavily starched.

R.T.P. Ref.	*Title and Journal*
	RUBBER
26242 U.S.A.	*The Use of Rubber for Producing Sheet Metal Parts.* (C. J. Frey and S.S. Kogut, Aero. Digest, Vol. 38, No. 1, Jan., 1941, pp. 116-21 and 235)
28980 Gt. Britain	*Summary of Current Literature on Rubber.* (J. of Rubber Research, Vol. 10, No. 8, Aug., 1941, pp. 501-569.)
1307 Gt. Britain	*Bibliography of Papers on Rubber in Aircraft Design.* (Compiled by Research Association of British Rubber Manufacturers.)
1541 U.S.A.	*Synthetic Rubber.* (O. M. Hayden, Mech. Eng., Vol. 64, No. 2, Feb., 1942, pp. 109-112.)

2266 U.S.A. *Cementing Rubber to Metal or Fabrics.* (Aero. Digest, Vol. 40, No. 1, Jan., 1942, p. 253.)

2276 U.S.A. *Tests Under Vibration of Rubber Mountings.* (Aero. Digest, Vol. 40, No. 1, Jan., 1942, p. 260.)

28169 SYNTHETIC OR NATURAL RUBBER

(Inter Avia., No. 766, 27th May, 1941, pp. 1-4)

Five different types of synthetic rubber are listed :—

(1) *Neoprene* (Polymers of chloroprene).
(2) *Thiokole* (Reaction products of aliphatic dihalides with alkali polysulfides).
(3) *Perbunan, Buna. S., Ameripols, Hycars, Chemigum* (Co-polymers of butadiene with other polymerisable compounds).
(4) *Koroseal* (Plasticised polymers of vinyl chloride).
(5) *Vistanex* (Polymers of isobutylene).

All of these differ chemically from natural rubber.

The purely mechanical properties of compositions of natural rubber are not surpassed to any marked extent by those of synthetic rubber stocks, so that in view of the present high production cost of synthetic rubber, it is improbable that synthetic rubber will replace the natural product in articles which depend for utility on such properties alone. It frequently happens, however, that in service rubber must be subjected to influences which rapidly impair its mechanical excellence. Often high temperatures, direct exposure to bright sunlight, or contact with oil cannot be avoided. In such cases compositions of synthetics or of mixtures of synthetics with natural rubber may result in certain improvements.

The synthetic products are superior to natural rubber in the following points :—

(*a*) Resistance to swelling and deterioration in contact with oils, organic solvents and water.
(*b*) Resistance to cracking in sunlight.
(*c*) Resistance to deterioration by heat.
(*d*) Resistance to powerful oxidising agents.
(*e*) Resistance to diffusion of gases.
(*f*) Possibility of compounding to graphite so as to render the product electrically conductory.

Natural rubber still exhibits superiority to all the synthetics now available in :—

(*a*) Elasticity and rebound.
(*b*) Low heat generation through hysteresis.
(*c*) Extensibility.
(*d*) Resistance to stiffening at low temperatures.

The synthetic rubber industry in Germany started on its way in 1934 with an annual output of ten tons, was claimed to have reached 4,000 tons already by 1937, and is now estimated to produce at the rate of about 60,000 tons annually. As a comparison, the American industry now produces only about 3,000 tons of synthetic rubber a year, the yearly consumption of natural rubber being of the order of 750,000 tons.

25914 RUBBERS NATURAL AND SYNTHETIC

(J. W. Schade, J. Aeron., Sci., Vol. 8, No. 5, March, 1941, pp. 177 and 182)

The meaning of the word rubber has changed since the advent of synthetic materials similar to the natural product. It is now used to designate a class of flexible, elastic materials rather than a particular hydrocarbon product of natural origin. The synthetic rubbers are classified into five types. The mechanical properties of all types are determined not by the kind of chemical elements composing them but rather by the arrangement of these elements, the size of the molecules and by structures produced by vulcanisation. All rubbers are modified by addition of other materials to fit them for a variety of uses. Differences in chemical composition and in the properties of natural and synthetic rubbers are shown in tabular form.

Mechanically, natural rubber is not surpassed by any synthetic rubber. However, in resistance to swelling by organic liquids, such as petrol and oils, and to deterioration by sunlight or oxidising agents synthetic rubbers have been found superior. These characteristics directed commercial applications to those fields where these properties are particularly needed.

2629 USES OF RUBBER IN WAR

(P. W. Drew, S.A.E.J., Vol. 50, No. 4, April, 1942, p. 41) (Digest)

American consumption of raw rubber is at present of the order of 800,000 tons per year, half of which is used for military purposes. Stocks amount to 650,000 tons and synthetic production is hoped to realise 500,000 tons per year within the next eighteen months.

The Chief military uses of rubber are listed below :—

Aircraft. Tyres, bullet sealing tanks, de-icers, life rafts, floatation gear, engine mounting, pipes, etc.

Tanks. Rubber tracks, solid tyres for track (boggie rollers) bullet sealing tanks, sponge padding, engine mounting, etc.

Trucks. Tyres, bullet sealing tanks, engine parts, etc. (In 1941, $11\frac{3}{4}$ million tyres were required for military vehicles. The 1942 consumption is estimated at eighteen million.)

Barrage Balloons. Fabric of these balloons is rubber coated.

Gas Masks.

Fire Hose and Fire Fighting Appliances.

In addition industry requires rubber for belts, hydraulic press pads, washers, commercial trucks, etc.

5597 SOME DYNAMIC PROPERTIES OF RUBBER

(C. O. Harris, J. App. Mech., Vol. 9, No. 3, Sept., 1942, pp. 129-135)

The purpose of the investigation described in this paper was to obtain information concerning the dynamic properties of rubber bonded to metal. Two properties of rubber were measured (*a*) the internal damping and (*b*) the dynamic modulus of elasticity. Two types of specimens were tested (*a*) rubber cylinders bonded to steel cylinders at the ends and stressed in compression and (*b*) specimens of rubber bonded to steel and stressed in shear. All specimens were of the same stock, 5140-V-4, manufactured by the U.S. Rubber Company. The hardness, as measured by the durometer, varied from 32 to 40. In the process of bonding to the steel, a $1\frac{1}{4}$ inch layer of 60 durometer stock was added adjacent to each piece of steel. This represents standard practice of the U.S. Rubber Company in bonding soft stock to metal. All specimens were cured for 30 minutes at 279°F.

1886

INDUSTRIAL PROGRESS IN SYNTHETIC RUBBERLIKE POLYMERS

(H. I. Cramer, Ind. and Eng. Chem. (Ind. Ed.), Vol. 34, No. 2, Feb., 1942, pp. 243-51)

The development of synthetic rubberlike polymers is being accelerated greatly by the national emergency. The annual production of these new vital materials has now increased to the point where it can be expressed in tens of thousands of tons.

Formerly the application of the synthetic rubbers depended upon their superiority in some specific respects over natural rubber. With the completion of the new plants now planned and under construction in the U.S.A. sufficient of the synthetic product should become available so that attention can be given to those applications involving simple replacement of the natural product.

Over a score of synthetic elastic polymers have been produced on a commercial scale. The discussion is limited to a review of the raw materials required, the commercial syntheses, applications, and costs of the polymers of butadiene or derivatives, the polybutenes, the alkylene polysulphides, and the plasticised polyvinyl chlorides,

The production capacity of synthetic rubber plants in the United States, built and in the course of construction, is discussed.

25445 BUTYL RUBBER

(R. M. Thomas, I. E. Lightbown, W. J. Sparks, P. K. Frolich and E. V. Murphree, Ind. and Eng. Chem. (Industrial Ed.), Vol. 32, No. 10, Oct., 1940, pp. 1283-1292)

This paper presents the results of a thoroughly unorthodox approach to the synthetic rubber problem. In developing their new butyl rubber, the Esso Laboratories have turned to simple olefins rather than diolefins or more complicated chemical derivatives as the main raw material. Not only is this an economic advantage, but the ready availability of such simple olefins from refinery cracking operations makes the process seem attractive from the standpoint of potential supply of synthetic rubber.

As only the limited amount of unsaturation required for curing with sulphur has been provided, the vulcanizates are substantially saturated and therefore possess the chemical stability characteristic of a paraffin hydrocarbon. In spite of this radical difference in internal structure, the polymer can be processed in much the same manner as natural rubber, and the physical properties of natural rubber have been retained to a surprising extent. Because of the low degree of unsaturation and consequent chemical inertness, the available information indicates that butyl rubber will be superior to natural rubber for many purposes.

25488

A NEW MATERIAL FOR GASKETS

(Autom. Ind., Vol. 83, No. 6, 15th Sept, 1940, pp. 265-6)

A new material for cylinder-head and other gaskets has been developed in Germany to take the place of asbestos-base gaskets (asbestos being a material not readily obtainable in Germany under present conditions). It is made up of three sheets or layers of the synthetic Buna rubber and two layers of steel-wire netting, the wires of the two layers being placed at angles of 45° with each other. Wire netting and rubber sheets are vulcanised together. Where the conditions of application make it desirable, metallic edging may be applied where the gasket is exposed to high pressure. Unlike natural rubber, which softens when exposed to high temperatures, Buna has a tendency to " tighten," and it can withstand high temperatures much better than natural rubber. Owing to the elastic nature of the rubber and the fact that the gasket is not coated with graphite, it is said to have better holding properties than conventional gaskets. The new gaskets are said to be resistant to hot water and hot oil up to 350° F., to glycol, gasoline, and leaded gasoline. They are not destroyed by adhering to the metal parts.

R.T.P. Ref.	*Title and Journal* **DEVELOPMENTS IN BASIC WORKSHOP PROCESSES**
2861 Gt. Britain	*Impact Extrusion in Practice.* (Light Metals, Vol. 4, No. 52, May, 1942, pp. 177-184.)
3410 U.S.A.	*High Production High Economy Methods for Metal Parts, (Casting, Forging, Welding, etc.).* (D. Basch, Am. Soc. Nav. Engineers, Vol. 54, No. 2, May, 1942, pp. 218-258.)
2859 Gt. Britain	*Bending Light and Ultra-Light Alloy Sheet (Continental Practice).* (Light Metals, Vol. 4, No. 52, May, 1942, pp. 171-174.)

27827

A NEW PROCESS FOR SHAPING TUBING TO ANY DESIRED CONTOUR

(Mchy., 12th June, 1941, pp. 287-90)

Particulars are given of a new process for forming tubing to almost any regular or irregular outline, including straight tapered and rounded portions. The process is stated to be applicable to welded and seamless steel tubes up to 4 inch outside diameter and $\frac{3}{16}$ inch wall thickness in addition to non-ferrous materials. Larger tubing could be handled by a machine of greater capacity or by hot working. Tolerances of plus or minus 0.010 inch with respect both to tube diameter and wall thickness are claimed to be attainable.

(Abstract supplied by Research Dept., Met.-Vick.)

27705

EFFECT OF SURFACE FINISH

(J. T. Burwell and others, J. App. Mech., Vol. 8, No. 2, June, 1941, pp. 49-58)

Surface finishes produced in various ways having roughnesses ranging from 130 to 1 microinch (as measured by their root-mean-square deviations from a median plane) have little or no effect on the performance of a partial journal bearing while it is operating under hydro-dynamic lubrication. There is general agreement with theory in this region but the agreement is improved if account is taken of the breaking of the film near the outlet end of the bearing.

The lower limit of the region of hydrodynamic lubrication for a given journal-bearing combination as indicated by the minimum in the friction-coefficient curve is markedly dependent on the surface finish of the journal. The load capacity of the bearing increases with increasing smoothness and this emphasises the great importance of reducing the surface roughness to less than 15 microinches at least.

A sensitive method of determining iron in oil has been developed, involving the extraction of the iron from the oil by means of hydrochloric acid. This permits the determination of 1 part of iron in 10,000,000 parts of oil. This method was applied to the study of the wear-in of a journal-bearing combination.

The effect of pressure on the running-in process was studied while maintaining a constant surface finish. The results indicate that the wear at the end of two hours increases with pressure for the pressure range up to 1,000 psi and the conditions obtaining in these studies.

The effect of surface finish on the running-in process was measured at constant pressure. A remarkable straight-line relationship exists between the total wear at the end of two hours and the degree of surface, finish at the constant pressure employed.

It was found that the running-in period takes place in a short time (of the order of one half to one hour). The initial rate of wear is high and falls off fairly rapidly. In all cases the quantity of metal removed was quite small, being less than a millionth of an inch if it could be considered as being removed uniformly.

25598

IMPROVEMENTS IN CUTTING OILS

(A. G. AREND, Chem. and Ind., Vol. 59, No. 46, 16th Nov., 1940, pp. 771-772)

Cutting oils are expected to minimise the power consumed, provide lubrication between the tool and the work, dissipate heat and cool both metal surfaces, increase the life of the tool, flush away turnings and chips, and prevent corrosion.

For reliable film strength, lard oils, mineral-lard oil blends, and sulphurised oils predominate, but lard oil has a good record for most metals for purely cutting purposes. Cotton-seed oil, although it has certain chemical disadvantages, is considered the best representative of the vegetable oils, whereas what are known as " straight " mineral oils very largely owe their popularity to the economy gained, rather than to any special qualities.

To-day, alkaline solutions are only to be seen in use in certain grinding operations to assist in cooling, and laying the dust, rather than in any cutting or lubricating capacity.

The introduction of sulphur to cutting oils produced a marked change, as almost any class of steels could be machined at any desired speed, and thus obviated the need for making frequent changes of the liquid medium. When properly compounded, the property of oiliness is sometimes even greater than that of pure lard oil, and the increased film strength is thought to be due to the affinity which sulphur in combination with oil has for metals.

After making analysis of a number of sulphurised oils it was found that the total sulphur content seldom exceeded 2%, but with others of a much richer type, a certain sulphurous corrosion appeared on the metal, which with the cutting edges of fine tools is apt to be serious.

One method of testing whether one type of cutting oil is better than another is to take observations of the kind of chips removed by the tool, and lengthy curling chips which bear heavily on the tool suggest the need for a heavily compounded sulphurised oil, while chips which break off hard indicate that a plain compounded oil, or at least lightly sulphurised oil will suit the purpose best. Successful production of cutting oils very largely depends upon co-operation between the engineer and the oil-manufacturing firm, so that all features of working at the greatest speeds will be given every consideration at the present time.

R.T.P. Ref.	*Title and Journal*
	RIVETING
25956 Gt. Britain	*Taper Bore Rivets.* (Airc. Prod., Vol. 3, No. 37, Jan., 1941, p. 25.)
25957 Gt. Britain	*Rivets from Light Alloy Sheet.* (Airc. Prod., Vol. 3, No. 27, Jan., 1941, p. 26.)

R.T.P. Ref.	Title and Journal
	Riveting—*continued*
26991 Switzerland	*New Developments in Riveting Light Metal Aircraft Structures.* (A. V. Zeerleder Flugwehr and Technik., Vol. 2, No. 5-6, May/June, 1940, pp. 120, 123.)
28678 Germany	*Automatic Riveting in Aeroplane Construction.* (*M.A.P.*) *translation* 1190. (Airc. Eng., Vol. 13, No. 151, Sept., 1941, pp. 257-60.)
28706 Gt. Britain	*The Dale Rivet for Flush Riveting Aircraft Structures.* (Airc. Prod., Vol. III, No. 35, Sept., 1941, p. 326.)
28368 U.S.A.	*Du Pont Explosive Rivet.* (D. L. Lewis, Chem. and Ind. (News Edition), Vol. 19, No. 14, 25th July, 1941, pp. 782-783.)
28371 U.S.A.	*Explosive Rivets.* (Autom. Ind., Vol. 85, No. 2, 15th July, 1941, pp. 31 and 70.)
29068 U.S.A.	*Automatic Riveting Machine for Aircraft Assembly.* (Aero. Digest, Vol. 38, No. 5, May, 1941, p. 222.)
29115 Switzerland	*Automatic Riveting in Aircraft Construction.* (A. von Zeerleder, Flugwehr und Technik, Vol. III, No. 7, July, 1941, pp. 164-166.)
29263 U.S.A.	*Advantages of the New Explosive Rivets.* (D. L. Lewis, Aero. Digest, Vol. 39, No. 2, Aug., 1941, pp. 183 and 228.)
478 Gt. Britain	*Automatic Riveting.* (*R.T.P. Translation No.* 1339). (A. V. Zeerleder, Airc. Eng., Vol. 14, No. 155, Jan., 1942, pp. 23-24.)
650 U.S.A.	*Explosive Rivets.* (Aviation, Vol. 40, No. 11, Nov., 1941, p. 125.)
860 U.S.A.	*Rivnut—A New Type of Blind Rivet* (*Used on Goodrich De-icers*). (R. H. Gill, Aero. Digest, Vol. 39, No. 6, Dec., 1941, pp. 232-235.)
2260 U.S.A.	*Tubular Blind Rivet.* (Aero. Digest, Vol. 40, No. 3, March, 1942, p. 322.)
2915 Gt. Britain	*The Dubilier Rivet.* (Airc. Prod., Vol. 4, No. 40, Feb., 1942, p. 217.),
3039 Gt. Britain	*New Designs of Holders-on for Light Alloy Sheet Riveting.* (Light Metals, Vol. 4, No. 53, June, 1942, pp. 230-231.)
3207 U.S.A.	*New Tubular Blind Rivet.* (J. J. Russell, Aero. Digest, Vol. 40, No. 5, pp. 239-240, May, 1942.)

27026

AUTOMATIC RIVETING IN AIRCRAFT CONSTRUCTION

(C. H. Plock, Luftwissen, Vol. 8, No. 2, Feb., 1941, pp. 36-42) (R.T.P. Translation No. 1190)

The article deals with flush riveting as practised by the Focke-Wulf Company. Such rivets can either be of the mushroom or flat head type. In the former, the rivet is inserted from the inside and the countersunk head produced from the rivet shaft previously cut to the exact length to produce a flush fit in the dimpled sheet. The flat head rivet is inserted from the outside, the closing head being produced on the inside without requiring exact dimensioning of rivet length. In plates over 1.2 mm. thickness, the countersink is normally produced by a special tool akin to a milling cutter, the operation being usually combined with the drilling of the rivet hole. For thinner plates, the necessary deformation for the countersink is produced mechanically (dimpling) either by the rivet itself or by means of special tools. If a thin outer skin is to be attached to a thicker plate, the latter is machine countersunk whilst the former is pressed to shape, again either by the rivet itself or by a special tool prior to insertion of the rivet. Dimpling by means of the rivet is more economical but the special

tool furnishes a smoother surface. In the simple riveting machine, the operation is limited to the closing of the rivet, either by gradual pressure (air, oil or a combination), a single blow or multiple blows. A semi-automatic riveting machine combines insertion with dimpling and clenching in one operation. An "automatic" riveter includes drilling the hole whilst a fully automatic machine also incorporates a work feed. It is also possible for the machine to manufacture the rivets as wanted by cutting off suitable lengths of wire carried on a reel. Representative types of semi and fully automatic machines are illustrated, and an interesting optical device for facilitating alignment of rivets with previously drilled holes is described.

Whilst the simple closing press requires but little operative skill, automatic riveting machines are much more delicate and trained personnel is essential. In the author's opinion, however, the saving in time is such that the high first cost of the automatic is well worth while.

26910

MECHANICAL PROPERTIES OF FLUSH RIVETED JOINTS

(W. C. Brueggeman, F. C. Roop, N.A.C.A., Report No. 701, 1940)

The strength of representative types of flush-riveted joints has been determined by testing 865 single-shearing, double-shearing, and tensile specimens representing seven types of rivet and eighteen types of joint. The results, presented in graphic form, show the stress at failure, type of failure, and d/t ratio. In general, dimpled joints were appreciably stronger than countersunk or protruding-head joints, but their strength was greatly influenced by constructional details. The optimum d/t ratios have been determined for the several kinds of joints. Photomacrographs of each type show constructional details and, in several instances, cracks in the sheet.

27856

DOUGLAS METHOD OF FLUSH RIVETING THIN SHEETS FOR AIRCRAFT

(Aut. Ind., Vol. 84, No. 10, 15th May, 1941, p. 518)

The rivet has a cylindrical shank 3.1 mm. diameter with a conical head of 100° taper and 5.50 mm. maximum diameter. A very shallow cylindrical crown (depth .15 mm.) is provided on the head and this is stated to ensure a tighter fit during the subsequent closing process. The original volume of the head is 18.6 cu. mm. and the ratio of the original diameter to the original height is 4.78.

In setting the rivet, it is first inserted into the hole in the sheets with the shank extending into a tubular "bucking tool," the upper end of which is countersunk at 110.80. One or two blows of the hammer (impact of the order of 11 feet/lb.) suffice to dimple the sheets and seat the rivet. During this operation, the head diameter is increased to 6 mm. and the height reduced from 1.15 to 1 mm. The volume of the new head is now 16.9 mm. and the diameter/height ratio is increased to 6.0.

The final step consists in upsetting the shank of the rivet by a series of blows of a riveting hammer fitting snugly inside the cylindrical portion of the bucking tool. During this operation the dimpling hammer rests on top of the rivet head and acts as a countermass.

29858

CHERRY SELF-PLUGGING RIVET (INCORPORATING MANDREL) FOR BLIND RIVETING

(American Aviation, Vol. 5, No. 12, 15th Nov., 1941, p. 47)

The self-plugging Cherry rivet has a mandrel with an expanded section and a head on the blind side. In installation, the assembly is inserted into the rivet hole until the head of the hollow rivet takes its ordinary position relative to the material being joined. Through the use of the combination hydraulic and pneumatic gun, the expanded section on the blind side is pulled into the hollow body of the rivet, expands the shank and forms a tulip head in the back. The outside end breaks off during application and can be trimmed off with ordinary nippers. Aircraft factory tests are said to have indicated that one man (unskilled) can install and trim 540 Cherry rivets per hour.

The outstanding feature claimed for the part is its positive mechanical action. The force required to apply the rivet breaks the mandrel and accomplishes two results: it creates a clinching action, holding the two sheets together securely, and also it expands the rivet, causing the necessary pressure fit of the shank.

R.T.P. Ref.	Title and Journal
	STAMPING, PRESSING AND DROP HAMMER WORK
25935 U.S.A.	*Forgings for Aircraft Structures.* (S. K. Oliver, Metal Progress, Vol. 38, No. 4, p. 515.)
26265 Germany	*Pressings in Aeroplane Construction.* (E. J. Ritter, Luftwissen, Vol. 5, No. 7, July, 1938) (Airc. Eng., Vol. 13, No. 144, Feb., 1941, pp. 45-7 and 54.)
26303 U.S.A.	*Forming and Stamping Aircraft Parts : A Survey of Press Tool Technique as Practised in America.* (Airc. Prod., Vol. 3, No. 28, Feb., 1941, pp. 59-64.)
27455 Gt. Britain	*Rubber Die Pressing.* (Airc. Prod., Vol. 111, No. 32, June, 1941, pp. 213-215.)
28066 Gt. Britain	*A Six Station Rubber Die Sheet Metal Press.* (Airc. Prod., Vol. 111, No. 34, Aug., 1941, p. 283.)
28083 U.S.S.R.	*Drop Forging with Cast Iron Dies.* (A. M. Kitaev, Aircraft Industry, U.S.S.R., Vol. 1, No. 13, April, 1941, pp. 2-4.)
28227 Gt. Britain	*The Drawing of Aluminium (Press Capacity, Sheet Temper, Design of Tools, etc.* (I. Stewart, Metal Industry, Vol. 59, No. 3, 18th July, 1941, pp. 34-36.)
28613 Gt. Britain	*Deep Drawing and Pressing of Al. and Light Alloy Sheets.* (J. D. Jevons, Metal Industry, Vol. 59, No. 9, 29th Aug., 1941, pp. 130-132.)
28822 Gt. Britain	*Deep Drawing and Pressing of Al. and Light Alloy Sheets (Part III), Magnesium Alloys.* (J. D. Jevons, Metal Industry, Vol. 59, No. 14, 3rd Oct., 1941, pp. 210-11.)
28825 Gt. Britain	*Deep Drawing and Pressing of Al. and Light Alloy Sheet* (1) (*Al. and Non-Precipitation Hardening Alloys.*) (J. D. Jevons, Metal Industry, Vol. 59, No. 10, 5th Sept., 1941, pp. 146-148.)

27420

EFFECT OF AGEING ON MECHANICAL PROPERTIES OF ALUMINIUM-ALLOY RIVETS

(F. C. Roop, N.A.C.A., Tech. Note 805, April, 1941, pp. 1-24)

The ratio of shearing strength to tensile strength of undeformed wire remained constant, for each alloy tested, independent of ageing time at room temperature. This ratio varied from 0.60 to 0.70 and the higher the tensile strength the lower the ratio, in the order : 24S-T, 17S-T, A17S-T, 53SW. The ageing times at room temperature required for undeformed wire of each alloy to reach practically its final value of strength were, approximately : 24S, 7 hours ; 17S, 3 days ; A17S, 8 months ; 53S, more than 2½ years. The strength of 17S material did not begin to increase until after an incubation period of about 1-2 hour.

The ageing times at room temperature required for rivets driven before ageing to reach practically their final strengths were, approximately, 24S, 3 months ; 17S, 1½ years ; A17S and 53S, more than 2½ years. 95% of their final strength was attained by rivets of alloys 24S and 17S, driven before ageing, after approximately 1½ days and 6 weeks ageing time, respectively.

The immediate effect on strength of the cold work involved in driving rivets was sometimes an increase, sometimes a decrease, depending on the alloy and the ageing time before driving. The effect on subsequent ageing of this cold work was in all cases a retardation, except only that there was no incubation period for 17S rivets driven before ageing. Thus, for a given total ageing time after quenching, rivets driven after ageing were always stronger than those driven before. Data covering considerably longer ageing times would be required to determine certainly whether the final strength attained by a rivet driven before ageing is less than that of undeformed wire.

The final values of driving stress for A17S and 53S rivets were reached after ageing times of approximately 6 months and $1\frac{1}{2}$ years, respectively. The final driving stress for A17S-T rivets was slightly higher than that required for 17S rivets immediately after quenching. The final driving stress for 53SW rivets was slightly higher than that for A17S rivets immediately after quenching. The high driving stress required for a standard conepoint head on a 24S rivet driven immediately after quenching resulted in frequent crack formation.

Precipitation heat treatment of alloy 53S had to be carried out immediately after quenching to obtain the highest possible strength values. No further ageing of this alloy occurred after precipitation heat treatment. The strength of a 53S-T rivet after precipitation heat treatment was about the same as that of a 17S rivet immediately after quenching or of a freshly driven A17S rivet—driven after ageing one day. The driving stress required for a 53S-T rivet was about the same as for an A17S-T rivet driven after ageing 4 or 5 hours.

TABLE I.

Rivet Alloys included in this Investigation

Alloy designation	Composition type	Grade (Navy Dept. Specification 43R5d)	Normal driving condition	Solution Heat-treatment temperature
24S	Al-Cu-Mg (1.5%)-Mn	D	As quenched	920° ± 10° F.
17S	Al-Cu-Mg-Mn	C	„	940° ± 10° F.
A17S	Al-Cu-Mg	F	Aged	940° ± 10° F.
53S	Al-Mg-Si-Cr	E	„ (or precipitation heat-treated)	970° ± 10° F.

TABLE II.

Chemical Composition of Rivets

Alloy designation	Chemical composition (%)					
	Cu	Mg	Mn	Si	Cr	Fe
24S	4.5	1.4	0.62	0.17	—	0.27
17S	4.1	.49	.52	.27	—	.60
A17S	2.4	.29	.01	.38	—	.40
53S	.03	1.2	.01	.66	0.23	.22

R.T.P. Ref.	*Title and Journal*
	Stamping, Pressing and Drop Hammer Work—*continued*
28905 Gt. Britain	*Deep Drawing and Pressing of Aluminium and Light Alloy Sheet (Part IV), Shaping Under the Drop Stamp and Air Hammer.*) (J. D. Jevons, Metal Industry, Vol. 59, 10th Oct., 1941, pp. 230-232.)
28999 Canada	5,000 *Ton Hydraulic Press for Fuselage Parts.* (Canadian Aviation, Vol. 14, No. 6, June, 1941, p. 56.)
29289 Gt. Britain	*Deep Drawing and Pressing of Al. and Light Alloy Sheet,* II. (J. D. Jevons, Metal Industry, Vol. 59, No. 13, 26th Sept., 1941, pp. 197-199.)
29409 Gt. Britain	*Deep Drawing and Pressing of Al. and Light Alloy Sheet (VI). (The Use of Rubber for Press Tools.)* (J. D. Jevons, Metal Industry, Vol. 59, No. 17, 24th Oct., 1941, pp. 265-266.)

R.T.P. Ref.	Title and Journal
	Stamping, Pressing and Drop Hammer Work—*continued*
688 Gt. Britain	*Deep Drawing and Pressing of Al. and Light Alloy Sheet (Part V), The German Process.* (Metal Industry, Vol. 59, No. 16, 17th Oct., 1941, pp. 245-47.)
2527 U.S.A.	*The Mechanics of Deep Drawing Sheet Metal Parts.* (G. Brewer and M. Rockwell, Aero. Digest, Vol. 40, No. 2, Feb., 1942, pp. 126-135.)
2911 Gt. Britain	*Plastics for Dies.* (Airc. Prod., Vol. 4, No. 40, Feb., 1942, p. 211.)
3006 U.S.A.	*Speeding Up Deep Drawing of Aircraft Parts.* (C. C. Misfeldt, Aviation, Vol. 41, No. 3, March, 1942, pp. 64-65, 203.)
3325 Gt. Britain	*Cold Pressing Properties of Dural Sheets (Discussion).* (J. Inst. Metals, Vol. 68, No. 6, June, 1942, pp. 209-214.)
3327 Germany	*Sheet Metal Presses for Forming Aircraft Parts.* (O. Ockl, Progressus, Vol. 7, No. 3, Mar., 1942, pp. 227-229.)

2465

THE COLD PRESSING PROPERTIES OF DURAL TYPE ALLOY SHEETS WITH SPECIAL REFERENCE TO THE PRODUCTION OF LARGE PRESSINGS FOR AIRCRAFT

(J. C. Arrowsmith and others, J. Inst. Metals, Vol. 68, No. 4, April, 1942, pp. 109-132)

An account is given of the difficulties experienced in the cold pressing of Duralumin type alloy sheet. The distortion which results from the heat treatment of the material is described, together with the methods for limiting its extent and overcoming its effect. Low ductility and a high degree of " spring-back " make the Duralumin-type alloys less amenable to cold pressing than is mild steel, and methods necessary for the production of the more difficult pressings are discussed.

Attention is drawn to the fact that maximum ductility is not obtained immediately after the water-quenching operation and a series of tests is described which shows that the ductility rises to a maximum after an interval of time which is dependent upon the temperature of storage, and then falls continuously as age-hardening proceeds. This interval of time is of the order of ten minutes at room temperature and two hours at the normal temperature of refrigerated storage ($-6°$ to $-10°$ C.). The effect can be used to advantage in the production of the most difficult pressings.

Evidence is given which shows that a fairly reliable indication of the deep-drawing properties of Duralumin-type alloys is to be found in the microstructure and the value for percentage elongation obtained in the tensile test carried out on freshly solution-treated material.

Mention is made of the success which has attended a deliberate attempt to produce material possessing the type of microstructure which had been found to be associated with good deep-drawing properties.

29827

HIGH PRESSURE HYDRAULIC PRESS FOR LARGE AIRCRAFT PARTS

(Luftwissen, Vol. 8, No. 10, October, 1941, p. 304)

A photograph shows the 8,000 ton hydraulic press of the Henschel Aircraft Works in operation turning out fuselage parts.

The useful rubber surface amounts to $3{,}700 \times 1{,}750$ mm., i.e., nearly 6.5 m. This is increased to 12.6 m^2 if the pressing is carried out metal to metal without insert. The weight of the press without pumping installation amounts to 375 tons. The three electric motors deliver a total of 270 h.p. and drive two 3-stage pressure pumps.

The maximum rate of operation is 6 to 8 mm/sec. at an excess pressure of 300 atmospheres. The return stroke is carried out at about 20 times this speed.

The height of the press (10 metres) necessitated a special hangar which was constructed round the press whilst the latter was being erected.

28869

PHOSPHATE COATINGS FACILITATE THE COLD WORKING OF METALS

(H. FABER and H. KOPP, Korrosion und Metallschutz, Vol. 17, No. 6, June, 1941, pp. 211-214)

During the cold working of metal, such as the drawing of tubes and rods and the deep drawing of containers, considerable friction is necessarily set up between the surface of the material and the die. In order to reduce wear of the die and seizure of the material it has been customary to use certain oils and fats as lubricants. The difficulty is to ensure adhesion of the lubricant under these arduous conditions, and although it is usual to roughen the surface of the material between the various stages of the process, the oil film will tear unless the rate of working is carefully adjusted. It has been discovered recently by Singer that the retention of the lubricant can be vastly improved, if the material is coated with a phosphate layer prior to drawing. A zinc phosphate deposit by the Bonder process has been found specially suitable and is covered by the German Patent 673405. The thickness of the deposit will depend on the degree of deformation required. In the case of tubes, one coating will generally last up to five consecutive drawings. In many cases it is thus possible to reach the final dimensions without a reheating of the material. Examples are given of electrically welded steel tubes (S.M. Steel of 35/40 Kg/mm^2 tensile), which were drawn in this way in five stages from an original diameter of 26 mm. and 1.2 mm. thickness to 16 mm. diameter and .6 mm. thickness. This implies a reduction in area of cross-section of 69%. Even more spectacular results were obtained with Cr-Mo steel (cross-section reduced by over 80% in five stages without reheating).

The process has also been applied successfully to pressure vessels, wire drawing, "upsetting" of screw heads, etc., and in the authors' opinion constitutes one of the outstanding discoveries of recent times.

R.T.P. Ref.	*Title and Journal*
	DIE AND PRESSURE CASTING
2703 Gt. Britain	*Gravity Die-Casting. A Comparison with Sand Casting.* (G. W. Lowe, Metal Industry, Vol. 60, No. 21, 22nd May, 1942, pp. 353-354.)
3549 Gt. Britain	*Comparison between Gravity and Pressure Die Casting.* (G. W. Lowe, Metal Industry, Vol. 60, No. 26, 26th June, 1942, pp. 433-434.)
	STRETCHING
201 Gt. Britain	*Stretch Pressing for Large Skin Sections.* (Airc. Prod., Vol. 4, No. 39, Jan., 1942, pp. 121-126.)
	SPINNING
2734 Gt. Britain	*The Spinning of Monel and Nickel Sheet.* (Engineering, Vol. 153, No. 3985, 29th May, 1942, p. 430.)
	WELDING
25903 U.S.A.	*Spot-Welding in Aircraft Construction. Details of American equipment and Design. (Paper to Amer. Welding Socy.)* (C. F. Marschner, Metal Industry, Vol. 57, No. 24, 13th Dec., 1940, pp. 506-9.)
25930 U.S.A.	*Electric Arc Welding.* (W. J. Chaffee, Metal Progress, Vol. 38, No. 4, Oct., 1940, p. 489.)
25931 U.S.A.	*Resistance Welding.* (E. J. del Vecchio, Metal Progress, Vol. 38, No. 4, Oct., 1940, p. 490.)
25932 U.S.A.	*Oxy-Acetylene Welding.* (J. H. Zimmerman, Metal Progress, Vol. 38, No. 4, Oct., 1940, pp. 491-2.)
25933 U.S.A.	*Atomic Hydrogen Arc Welding.* (R. F. Wyer, Metal Progress, Vol. 38, No. 4, Oct., 1940, pp. 493-4.)
25955 Gt. Britain	*Welding of Air Frames.* (W. S. Corns, Airc. Prod., Vol. 3, No. 27, Jan., 1941, pp. 21-25.)

R.T.P. Ref.	*Title and Journal* **Welding**—*continued*
25958 Gt. Britain	*Finishing Stainless Steel Welds.* (Airc. Prod., Vol. 3, No. 27, Jan., 1941, pp. 32-33.)
26266 Germany	*Spot Welding Development at the Arado Works.* (E. Riechel, Jahrbuch der Deutschen L.F.F., Vol. 1, 1938, pp. 538-48.)
26267 Germany	*Junkers Experiments in Spot Welding.* (W. Borstel, Junkers Nachrichten, Vol. 9, No. 7, July, 1938.) (Airc. Eng., Vol. 13, No. 144, Feb., 1941, pp. 55-6.)
26381 Gt. Britain	*Investigations on the Spot Welding of Light Alloys.* (*Report of the Welding Research Council of the Institute of Welding.*) (G. H. Field and H. Sutton, Airc. Prod., Vol. 3, No. 29, March, 1941, p. 101.)
26382 Gt. Britain	*Half-Cycle Bench Mounting Spot-welding Machine for Welding of Small Parts.* (Airc. Prod., Vol. 3, No. 29, March, 1941, p. 104.)
26419 Gt. Britain	*Spot Welder using Magnetic Storage* (*Sciaky*). (Electrical World, 25th Jan., 1941, pp. 44-5.) (Met.-Vick. Tech. News Bull., No. 752, 7th March, 1941, p. 2.)
26590 Gt. Britain	*The Welding of Air Frames, Part* III, *Directional Welding.* (W. Corns, Airc. Prod., Vol. 3, No. 30, April, 1941, pp. 135-138.)
27447 Gt. Britain	*Spot Welding of Light Alloys.* (Airc. Prod., Vol. 3, No. 32, June, 1941, p. 190.)
27457 Gt. Britain	*Spot Welding in Aircraft Production.* (Airc. Prod., Vol. 3, No. 32, June, 1941, p. 218.)
27561 Switzerland	*The Present State in the U.S.A. of Welding Technique for Aircraft Construction.* (L. P. Wood, Flugwehr und Technik, Vol. 2, No. 10, Oct., 1940, pp. 234-236.)
28069 Gt. Britain	*A New Spot Welder for Al. Alloy Sheets.* (Airc. Prod., Vol. 3, No. 34, Aug., 1941, p. 295.)
28148 U.S.A.	*Application of Spot Welding to Aircraft Production.* (M. Rockwell, J. of S.A.E., Vol. 48, No. 6, June, 1941, p. 26.)
28156 Gt. Britain	*The Welding of Non-Ferrous Metals.* (West. Trans. Inst. Weld., April, 1941, pp. 76-112.) (Met.-Vick., Tech. News Bull., No. 770, 11th July, 1941, p. 9.)
28403 Gt. Britain	*Forging v. Welding in Aircraft Construction.* (Metal Industry, Vol. 59, No. 5, 1st August, 1941, p. 65.)
28681 Gt. Britain	*Welding Jigs.* (Airc. Eng., Vol. 13, No. 151, Sept., 1941, p. 265.)
29003 Canada	*Spot Welding in Plane Production* (*Experiments by Bell Aircraft with Sciaky Spot-welder*). (Canadian Aviation, Vol. 14, No. 6, June, 1941, pp. 48-49.)
29028 U.S.A.	*Development of Aircraft Spot Welding.* (M. M. Rockwell, Aviation, Vol. 40, No. 7, July, 1941, pp. 42-43 and 162.)
29029 U.S.A.	*Electric Arc Welding of Aircraft Structure.* (R. Thorne, Aviation, Vol. 40, No. 7, July, 1941, pp. 44-45 and 164.)
29043 U.S.A.	*Channel and Stiffener Sections for Spot Welding.* (Aviation, Vol. 40, No. 7, July, 1941, p. 127.)

R.T.P. Ref.	*Title and Journal*
	Welding—*continued*
29276 U.S.A.	*High-speed Production Spot Welding of Al. Alloy.* (Aero. Digest, Vol. 38, No. 4, April, 1941, pp. 121-2.)
29591 Germany	*Resistance Welding of Light Alloy Parts in Aircraft Construction.* (R. Schnarz, Luftwissen, Vol. 8, No. 9, Sept., 1941, pp. 270-276.)
29877 Gt. Britain	*Spot Welding (Testing, Control and Supervision).* (*Various Authors, Welding J., Oct.,* 1941, *pp.* 478-482, 491-498, 673-677 *and* 687-693.) (Abstract in Met.-Vick. News Bull., No. 790, 28th Nov., 1941, pp. 10-12.)
29882 U.S.A.	*Inspection of Spot Welded Assemblies.* (Metal Progress, Vol. 40, No. 4, Oct., 1941, pp. 659.)
544 Gt. Britain	*Portable Spot Welding Machine.* (Engineering, Vol. 153, No. 3968, 30th Jan., 1942, p. 96.)
686 Gt. Britain	*The Welding of Light Alloys* (II). (E. G. West, Metal Industry, Vol. 59, No. 20, 14th Nov., 1941, pp. 312-313.)
705 Gt. Britain	*The Welding of Light Alloys.* (E. G. West, Metal Industry, Vol. 59, No. 19, 7th Nov., 1941, pp. 294-296.)
810 U.S.A.	*Procedure Control for Aircraft Welding* (II). (A. K. Seemann, Aviation, Vol. 40, No. 12, Dec., 1941, pp. 116-117 and 210.)
870 U.S.A.	*Portable Arc Welding for Thin Gauge and Aircraft Welding (G.E.C.).* (Aero. Digest, Vol. 39, No. 6, Dec., 1941, p. 252.)
1374 U.S.A.	*Review of Present-day Welding of Aircraft Steels.* (A. J. Williamson and J. P. Dods, Inst. of Aeron. Sci., 10th Annual Meeting, Jan., 1942, pp. 1-10.)
1512 Gt. Britain	*Portable Spot Welding.* (Mech. World, 23rd Jan., 1942, p. 83.) (Met.-Vick. Tech. News Bull., No. 800, 6th Feb., 1942, p. 8.)
1514 Gt. Britain	*High-speed Welding Electrodes.* (de Lange and Waddington, Weld. Ind., Jan., 1942, pp. 287-289.) (Met.-Vick. Tech. News Bull., No. 800, 6th Feb., 1942, p. 11.)
1537 Gt. Britain	*Spot Welding of Light Alloys.* (Metal Industry, Vol. 60, No. 10, 6th March, 1940, p. 182.)
1742 Gt. Britain	*The Testing of Welds.* (H. N. Pemberton, Electrician, Vol. 128, No. 3328, 13th March, 1942, pp. 226-28.)
1841 Gt. Britain	*Testing of Welds.* (H. N. Pemberton, Engineer, Vol. 173, No. 4,500, 10th April, 1942, pp. 315-316.)
2272 U.S.A.	*Welding in Construction and Maintenance of Aircraft.* (A. K. Seemann, Aero. Digest, Vol. 40, No. 1, Jan., 1942, pp. 187-195.)
2855 Gt. Britain	*Modern Welding Technique (Memoranda issued by the Advisory Service on Welding, Ministry of Supply).* (Light Metals, Vol. 4, No. 52, May, 1942, p. 168.)
3021 U.S.A.	*Hobart Welders . . .* (Aviation, Vol. 41, No. 3, March, 1942, p. 105.)
3022 U.S.A.	*Progressive Welder.* (Aviation, Vol. 41, No. 3, March, p. 106.)
2906 Gt. Britain	*New Aircraft Arc Welder.* (Airc. Prod., Vol. 4, No. 40, Feb., 1942, pp. 208-209.)

3062 Gt. Britain — *A Survey of Aircraft Resistance Welding Equipment.* (Wood, Weld. Engr., Feb., 1942, pp. 33-37.) (Met.-Vick. Tech. News Bull., 813, p. 2.)

3076 U.S.A. — *Spot Welding Speeds Plane Output.* (P. Merriman, J.S.A.E., Vol. 50, No. 5, p. 44, May, 1942.)

2754

FLASH BUTT WELDING OF CHROME MOLYBDENUM STEEL

(W. S. Evans and V. Netchvolodoff, J. Aeron., Sci., Vol. 9, No. 6, April, 1942, pp. 207-212)

Flash butt welding of steel has been an established industrial process for many years. The automobile industry, in particular, has used this process to take advantage of the low cost, high rate of production and excellent physical properties of the weld.

Application of this process to chrome-molybdenum steels has been very limited, especially in the aircraft industry. Limiting factors for aircraft application have been a lack of production volume, necessary equipment and experience. A natural tendency on the part of aircraft designers has been to exercise caution in the use of processes deviating from long-established practices. In recent years, with the advent of large contracts, it has become advisable to investigate the possibilities of this process in structural design.

This article will give a brief outline of the many variables involved in the process, as well as part and die design. Only in recent years has any effort been made to determine the individual effect of the various factors involved with respect to aircraft steels. It should be remembered that this process as applied to chrome-molybdenum steel is in the development stage and many of the procedures used at the present time may be discarded as a result of further research and additional experience.

762

A.C. ARC-WELDING

(Potter, Welding Engineer, Dec., 1941, pp. 30-32)

Reasons for the increasing prominence of A.C. arc-welding as compared with D.C. processes are discussed in this article. For practically all types of mild steel fabrication, suitable electrodes are available. When such work permits the use of welding currents of 200 amperes or more, requiring $\frac{3}{16}$ inch diameter electrodes, A.C. welding is said to be unquestionably more economical. Defects such as slag inclusions and porosity, due to magnetic blow, may be more easily avoided with A.C. than with D.C. welding, whilst relative absence of "arc-blow" gives lower costs by making it feasible to use larger diameter electrodes and high currents, thus improving welding speeds. Also less time for training operators is claimed to be needed for A.C. systems, and low operation costs are obtained by higher electrical efficiency and less maintenance cost.

(Abstract supplied by Research Dept., Met.-Vick.)

28931

ARC-WELDING WITHOUT RESIDUAL STRESSES

(R. E. Spaulding, J. Am. Soc. Nav. Engs., Vol. 53, No. 3, Aug., 1941, pp. 675-79)

The process recommended consists in pressing or light hammering of the weld area while it is cooling (vibratory pressure is best or pressure only if welding process is continuous). This added pressure, applied at right angles to the axis of the weld, can usually be best accomplished by the use of a light pneumatic or electric hammer having a tool face adapted to the desired size and contour of the weld. If applied at the right time, that is, while the yield strength of the hot weld is relatively low, only a small amount of effort is needed and all shrinkage tendency is found to have been eliminated.

The new method must not be confused with so-called "peaning" or hammering of the weld area after it has cooled to such an extent that the elastic limit or yield strength of the area has again approximated that of the original metal. Nor should it be compared to reheating of the weld area, with or without treatment while heated, since no heat produced by a flame can even approximate the same relative heat penetration with corresponding surface intensity of that resulting from an electric arc. In both of these latter methods counter-balancing locked-in stresses may be introduced which will overcome warpage, but the welded assembly is, nevertheless, still subject to high internal stresses, and often the physical structure of the metal is disturbed and weakened.

1511

CONTACT RESISTANCE IN WELDING

(TYLECOTE, Weld. J. Supplt., Dec., 1941, pp. 591-602)

The fundamentals of plate-to-plate contact resistance in spot-welding are discussed, and methods and apparatus for its determination examined. After mentioning the "types" of contact area to be encountered, the author analyses initial investigations of surface conditions, and explains how resistance values were obtained by D.C. resistance measurements. The effects of pressure and upset pressure are outlined. A specially devised cathode ray oscillograph is then described in detail. It contains three gas-focused tubes for measuring respectively the potential drops between the two sheets to be welded, one sheet and an electrode, and the drop across a shunt placed in the electrode holder. Some particulars of the welder are given, and results obtained by welding materials with different surface treatments are analysed.

(*Abstract supplied by Research Dept., Met.-Vick.*)

25413

METROVICK RESISTANCE WELDING MACHINES

(DORRAT, M.V. Gazette, Sept., 1940, pp. 52-62)

Some of the special resistance welding machines devised by M.V. are described. Spot welding machines range from light-duty bench type welders, where pressure and length of weld are controlled by the operator, to the heavy-duty type, with which infinite variation of welding heat may be obtained by means of "phase control" incorporated in the ignition control system, and also, by electrically operated air valves, a definite pressure cycle may be applied during welding. The M.V. portable spot welding machine and the aircraft type spot-welding machine are also described. Butt welding machines, where correct balance between pressures, "push-ups" and welding currents is essential, and seam-welding machines are briefly reviewed.

29521

RESISTANCE WELDING OF LIGHT ALLOYS

(R. W. Research Committee, Aero. Res. Inst., Tokyo, No. 210, May, 1941, pp. 301-482)

The following are the factors controlling resistance welding :—

(1) Magnitude of welding current,
(2) Time of current flow,
(3) Mechanical pressure between electrodes,
(4) Material of electrodes,
(5) Shape of electrode tips,
(6) Material of the metal sheets to be welded,
(7) Thickness of the sheets,
(8) Surface conditions of the sheets.

An investigation of the resistance welding of light alloys is being carried on since 1936 at the Aeronautical Research Institute, Japan, with the collaboration of its five departments (Aircraft, Electrical Engineering, Materials, Metallurgy and Central Work Shop).

This report gives a general account of resistance welding of light metals and the results of the investigations on spot welding up to the present.

A good many of the authorities on the subject have reported that in producing satisfactory welds, three of the variables—welding current, time and pressure—must be accurately controlled. According to the experiments in the Aeronautical Research Institute, however, the shape of electrodes is considered to be one of the most critical variables, and the proper values of current, time and pressure cannot be recommended without the specification of the shape of electrodes.

At present, the static shear strength of welds is already satisfactory. Under shock, welds of 1.5 to 2.0 mm. thickness have shown equal or better results than with 5 mm. rivets.

Under fatigue, however, the weld is inferior to the riveted joint. Subsequent mechanical treatment can improve the strength characteristics of the weld and this is being investigated further.

25360

SUGGESTED METHODS OF TESTING SPOT WELDS

(Weld. J., Sept., 1940, pp. 333-334)

The article gives a summary of methods of testing recommended by the Resistance Welding Committee of the Welding Research Committee. The tests fall into two groups: (1) process qualification tests, (2) material weldability tests. In class (1) the main test is a tensile test from which the ultimate strength of one spot weld, the diameter of the weld slug, and manner of failure, are observed. Dimensions of the test specimens, and testing procedure are described in detail. The tensile test is to be supplemented by a visual test on a cross-section, chemical analysis, etc. In class (2) the standard lap shear test as used in (1) is to be supplemented by a tensile test on a U-shaped specimen. To ascertain whether fusion has taken place, as a preliminary to the standard tests, torsion tests and peel or pull-out tests may be employed.

(*Abstract supplied by Research Dept., Met.-Vick.*)

26010

STRENGTH OF SPOT WELDS

(Neuman & McCreery, Weld. Engr., Dec., 1940, pp. 28-31 and 42)

Investigations have been carried out by the authors on the strength determination of spot-welded joints. Such joints are found to be similar in many respects to riveted joints, but can carry more load. Resistance welding, with button electrodes, was used on the test pieces, attention being paid to correct pressure and timing. Certain conclusions are drawn from the data given, regarding the design of spot-welded joints and the factor of safety to be employed.

(*Abstract supplied by Research Dept., Met.-Vick.*)

28155

THE SPOT WELDING OF LIGHT ALLOYS

(Tylecote Trans., Inst. Weld., April, 1941, pp. 56-75)

Literature, published up to October, 1940, on the spot welding of light alloys is reviewed. The subject matter includes weldability, machines and machine settings, surface preparation, electrodes, strength properties, etc. A bibliography and author index are appended.

1512

PORTABLE SPOT WELDERS

(Mech. World, 23rd Jan., 1942, p. 83)

Features of portable spot-welding equipment are discussed and one of the main advantages is said to be the possibility of jig-assembling the work without the necessity for limiting the total weight. A Metrovick portable spot-welding machine is described, and some particulars of the control equipment given. It contains water-cooled transformer and secondary leads to the welding tongs, and has a special controller equipped with three synchronous mechanical timers. The machine also incorporates "Woodpecker Control," which is stated to produce very consistent welds and to reduce the deformation of the copper electrode tips.

(*Abstracts supplied by Research Dept., Met.-Vick.*)

29585

SPOT WELDING OF LIGHT ALLOYS

(Junkers Journal, Vol. 12, No. 5-6, May-June, 1941, pp. 59-69)

Spot welding of light alloy sheets has been successful, provided proper attention is paid to the preliminary treatment of the sheet and that the welding current and electrode pressures are suitable. Pure Al-Mg and Al-Si-Mg alloys are relatively easy to spot weld, although in the latter case, the heat-treated material will lose some of its strength in the weld zone. Al-Cu-Mg alloy sheet require the greatest care in the control of the current characteristics. Loss of strength due to softening can be made good by a closer spacing of the spots.

A thorough cleaning of the sheets prior to welding is essential. This can be carried out either by immersion in a caustic soda bath or by mechanical brushing. As already mentioned, control of the welding current is of the utmost importance. Experiments were carried out with different types of current pulses and rest periods. An alteration of the wave form during the welding process was found to be beneficial.

Thus for example, a successful current control adopted consisted of five periods at maximum amplitude alternating with five periods at 50% amplitude with rest periods (zero current) of five periods between the changes, one period = 1/50 sec. In this case there are two pulses per spot weld. Alternatively single pulse control can be adopted, the current rising to a maximum during five periods and then diminishing to zero over the next five periods. No details of the electronic controls are given. By proper timing of its pulses, it is apparently possible to work four or more machines from a single 350 KVA transformer, leading to a considerable saving in the cost of the plant. Types of electrode employed are described in some detail. Electrolytic copper appears to be the most suitable material. Means for rapid cleaning of the electrodes are essential. Interposition of a thin foil of brass between electrode and weld has been found very beneficial in this connection. The foil (in ribbon form) is moved automatically and carries away most of the impurities which would otherwise accumulate on the electrode.

29530

AIRCRAFT SPOT-WELDING PROBLEMS

(M. M. Rockwell, J.A.S.E., Vol. 49, No. 4, Oct., 1941, p. 441)

Aluminium alloys have low electrical resistance and high heat conductivity; hence very heavy welding currents and pressures must be used. Even then, most of the generation of heat occurs at the surface of contact between the sheets being welded.

These conditions have imposed difficulties which have somewhat retarded the application of spot-welding in the aircraft industry. However, of recent years development has come very rapidly.

The increase in requirements for spot-welding equipment in turn brought to the fore a very serious problem—the magnitude of the power supply necessary for such equipment.

At this point a saving factor appeared in the form of the "stored-energy" type spot-welder first introduced into the U.S.A. two years ago by a French firm. The "stored-energy" spot-welder introduces a new principle—that of charging the transformer up slowly with magnetic energy, then discharging it quickly to make the weld.

Consistent maintenance of the proper pressure is essential to successful spot-welding because pressure controls the surface contact resistance. In many machines pneumatic force is used to produce electrode pressure and, if the air lines to the welder are too small, the air pressure will drop when the machines are operated rapidly, and mysterious troubles will ensue. It was found necessary to install a large air receiver near the welders to overcome this trouble. Hydraulic pressure systems should be a helpful improvement.

Probably the greatest single cause of spot-welding trouble is improver surface preparation. Oil, grease, or paint left on the surfaces to be welded produce cracked, burned, weak, or even "blown" spots. Careful cleaning is essential and, in most cases, it is also necessary to remove part of the oxide film which always covers the surface of aluminium alloys.

26266

SPOT WELDING DEVELOPMENT AT THE ARADO WORKS

(E. Reichel, Jahrbuch der Deutschen Luftfahrtforschung, Vol. 1, 1938, pp. 538-48; (Translated in Airc. Eng., Vol. 13, No. 144, Feb., 1941, pp. 49-54)

Tests made with the A.E.G. electric welding machine, based on the principle of grid control and providing exact regulation of the current, have proved that welding can be substituted for riveting for joining parts of Hydronalium sheet. An important increase in fatigue strength of the welded parts can be obtained by subsequent annealing at 330° C. for sixty minutes. The fatigue strength then exceeds that of similar riveted parts. A large stressed component, in the form of the fuselage of a single-seat fighter, has been welded and tested in flight. Welding can also be used conveniently for aluminium components and for Elektron so long as the sheet thickness does not exceed 0.8 mm. For thicker Elektron sheet it proved advisable to anneal, shortly before welding, at 300° C. for five to ten minutes. Duralumin material has presented greatest difficulties in electrical spot and seam welding, and further research is required. By comparison with riveting, production may be increased two or three times by seam welding, while obtaining a considerable reduction in production costs.

25452

PULSATION WELDING

(COGAN and PELTON, Weld. Ind., Oct., 1940, pp. 249-50 and 252)

An outline is given of the technique of pulsation welding, and recent progress in this field is reviewed. Results of tests on pulsation welded joints are submitted and the following advantages are claimed for this method, especially with spot and projection welding: electrode life is increased, thicker material can be welded in production than was practicable before; thicker material can be welded with the same equipment; any tendency of the weld metal to "spit" is reduced; and the finished appearance of the weld is improved. A description is included of a vertical, hydraulically operated, pulsation butt-welding machine, with full synchronous electronic timing control.

Illustrated with one photograph.

(Abstract supplied by Research Dept., Met.-Vick.)

28499

FATIGUE TESTS OF WELDED JOINTS (UNIVERSITY OF ILLINOIS)

(W. M. WILSON and others, Nature, Vol. 148, No. 3748, 30th August, 1941, pp. 261-262)

The primary object of this Progress Report by the Engineering Department of the University of Illionois was to obtain reliable information on which to base specifications governing the design of welded structural members subjected to reversed or pulsating stresses. The lack of knowledge of the fatigue strength of welded joints has been the principal deterrent to their adoption in the fabrication of bridges, and it was clear that tests on the largest practicable scale would have to be made before this method of construction could be placed on a satisfactory and reliable basis.

Three kinds of stress cycle were used: (1) from a tensile stress to an equal compressive stress; (2) from zero stress to a maximum tensile stress; (3) from a maximum tensile stress to a minimum tensile stress of half the value. These gave ratios r, of -1.0 and $+0.5$ respectively, and for each value of r, seven identical specimens were tested; three so as to fail at 100,000 cylces, and three at 2,000,000 cycles, the seventh being a spare to be tested as desired after the other six tests had been completed.

It appears that the dependable strength of welded joints and plates weakened by transverse welds is quite moderate. Butt welds in $\frac{7}{8}$ inch carbon-steel plates in the as-welded condition failed after 2,000,000 cycles for maximum stresses of 14,400, 22,500 and 36,900lbs. per sq. inch in the three classes of cycle. The corresponding figures for machined-off specimens of classes 2 and 3 were 28,400 and 43,700 and for ground-off specimens of class 2 were 26,300. Stress-relief did not appear to affect fatigue strength, and periods of rest showed no advantage. Carbon-steel plates with one transverse fillet weld gave an average of 18,900 and with two welds 13,100 lbs. per sq. inch. The character of the bead had some effect on the figures, but for a given base metal the variation did not exceed 5%.

27826

AN INSIDE LOOK AT WELDS

(Baldwin Machinist, 7th June, 1941, pp. 149-52)

Particulars are given of the technique employed by the General Electric Company of Schenectady for the examination of welds by X-rays. The use of steroscopic location of flaws is explained and details given of the procedure and apparatus employed. A special technique has been developed for the G.E. welding school, where test plates are X-rayed in groups to keep cost at a minimum.

(Abstract supplied by Research Dept., Met.-Vick.)

26330

INCREASING THE DUCTILITY OF WELDS

(DAWSON AND LYTLE, Steel, 20th Jan., 1941, pp. 62-4)

A study has been made of the effect of heat treatment on the physical properties of oxyacetylene welds. The results recorded indicate that the ductility of the weld metal, as indicated by elongation and reduction of area under tensile load, can be improved 30 to 50% by treatment at lower temperatures than are ordinarily employed for stress-relieving treatment. According to the authors this improvement takes place in low alloy steels as well as in carbon steels.

(Abstract supplied by Research Dept., Met.-Vick.)

1509
HARDNESS AND MICROSTRUCTURE TESTS ON WELDS

(SPARAGEN AND CLAUSSEN, Weld. J. Suppl., Dec., 1941, pp. 561-602)

Continuing their review of literature on this subject to July, 1939, the authors discuss hardness of welded joints as it is affected by materials used, welding speed, current and electrode details, plate thickness, preheating, post-heating, carbon content, alloying elements, austenite grain size and weld-quench tests. Hardness as the criterion of weldability is analysed and existing correlations between hardness and tensile properties, bend ductility, microstructure and cracks of welds presented. Some particulars are then given of microstructure and macrostructure investigations.

(*Abstract supplied by Research Dept., Met.-Vick.*)

R.T.P. Ref.	*Title and Journal*
	SHEET METAL WORK
28707 Gt. Britain	*The Production of Anson and Hurricane Fuel Tanks.* (Airc. Prod., Vol. 3, No. 35, Sept., 1941, pp. 327-330.)
29846 U.S.A.	*Self-Sealing Fuel Tanks for Aircraft.* (American Aviation, Vol. 5, No. 10, 15th Oct., 1941, p. 41.)
2627 U.S.A.	*Crash Proof Fuel Tanks.* (T. W. Baird, S.A.E.J., Vol. 50, No. 4, April, 1942, p. 38.)
	RECTIFICATION OF MACHINE-SHOP ERRORS
2632 U.S.A.	*Building Up of Worn Parts.* (W. J. Cumming, S.A.E.J., Vol. 50, No. 4, April, 1942, pp. 139-140.)
	FINISHING PROCESSES
26296 U.S.A.	*Honed Microfinish for Aircraft Parts.* (Autom. Ind., Vol. 84, No. 2, 15th Jan., 1941, pp. 59-62 and 96.)
27454 Gt. Britain	*Surface Finish : The Honing Operation.* (Airc. Prod., Vol. 3, No. 32, June, 1941, pp. 209-212.)
	NEW USES OF SMALL TOOLS
26250 U.S.A.	*Consolidated's Tooling Methods Simplify Production.* (P. Koenig, Aero. Digest, Vol. 38, No. 1, Jan., 1941, pp. 156-9.)
26255 U.S.A.	*Modern Machinery for the Production of Aircraft and Engines.* (Aero. Digest, Vol. 38, No. 1, Jan., 1941, pp. 171-208)
29013 U.S.A.	*Machining Problems in Aircraft Construction.* (J. P. Johnson, Mech. Eng., Vol. 63, No. 5, May, 1941, pp. 346 and 356.)
3174 Gt. Britain	*Shop Equipment and Small Tools (Cable Markers, Cutter, Grinding, etc.).* (Airc. Prod., Vol. 4, No. 43, p. 362, May, 1942.)
	SHEET GRIPS AND CLAMPS
1018 Germany	*New Methods of Making Glued Repairs on Plywood Wing Covering for Aircraft (Use of the Needle Clamp).* (Luftwissen, Vol. 8, No. 12, Dec., 1941, p. 374.)
3106 Germany	*Detachable Metal Sheet Fastening.* (Luftwissen, Vol. 9, No. 4, pp. 120-121, April, 1942.)

Part III

MANUFACTURE OF WOODEN AIRCRAFT COMPONENTS

27861 U.S.S.R.	*Pneumatic Press for Sticking Aircraft Plywood.* (M. S. Karilin, Aviation Industry, No. 16, April, 1941, pp. 8-10.)
1389 U.S.A.	*Advances in Production and Assembly of Plywood in Aircraft Construction.* (H. G. Bersie and E. C. Clarke, Inst. Aeron. Sci., 10th Annual Meeting, Jan., 1942, pp. 1-23.)

R.T.P. Ref.	Title and Journal
	Manufacture of Wooden Aircraft Components—*continued*
2279 U.S.A.	*Troop Carrying Gliders.* (Aero. Digest, Vol. 40, No. 1, Jan., 1942, p. 299.)
3875 U.S.A.	*Wooden Aeroplanes in the U.S.A.* (Inter. Avia., No. 825-826, 21st July, 1942, pp. 12-13.)
3285 Gt. Britain	*Treatment of Timber by Urea.* (Engineering, Vol. 154, No. 3992, 17th July, 1942, p. 46.)
3585 U.S.A.	*Plywood for Aircraft.* (American Aviation, Vol. 5, No. 23, 1st May, 1942, p. 3.)

PLANES, SPARS, RIBS

28796 Gt. Britain	*Wooden Wings in Manufacture for Miles Trainer Aircraft.* (Airc. Prod., Vol. 3, No. 36, Oct., 1941, pp. 373-375.)

MANUFACTURE OF METAL AIRCRAFT COMPONENTS

1621 Gt. Britain	*Bibliography No. 1 on Metal Construction Applied to Aircraft (up to May, 1936). With Addendum No. 1 (up to Jan., 1938).*
3665 Gt. Britain	*Bibliography of Published Information on Stressed Skin Construction* (1939-1941). (R.T.P. 3, Bibliography No. 38.)

PLANES

3176 Gt. Britain	*Handley Page Halifax (Building Centre Section and Main Planes).* (W. E. Goff, Airc. Prod., Vol. 4, No. 44, pp, June, 1942. 384-393.)

FUSELAGE

26246 U.S.A.	*Analysing the Requirements of Supercharged Cabins.* (D. Gregg, Aero. Digest, Vol. 38, No. 1, Jan., 1941, pp. 136-43.)
26269 U.S.A.	*Pressurised Cabin Control.* (H. E. W. Tinker and H. S. Hubbard, Aviation, Vol. 40, No. 1, Jan., 1941, pp. 38, 119 and 124.)
26301 Gt. Britain	*Producing the "Shadow" Blenheim : Part II, Building the Front and Rear Sections of the Fuselage : Works Layout and Equipment.* (B. Foster, Airc. Prod., Vol. 3, No. 28, Feb., 1941, pp. 45-54.)

FITTINGS AND DETAIL PARTS

26313 Germany	*Gaskets in Aircraft and Engine Construction.* (H. Diegmann, Der Flieger, Vol. 20, No. 1, Jan., 1941, pp. 16-17.)
28965 Gt. Britain	*Self-Locking Nuts.* (Airc. Prod., Vol. 3, No. 33, July, 1941, p. 233.)

ASSEMBLY METHODS

25973 Gt. Britain	*Quantity Production of Whitley Bombers.* (Flight, Vol. 39, No. 1671, 2nd Jan., 1941, pp. 13-16.)
26251 U.S.A.	*Novel Assembly Methods for Boeing A-314.* (Aero. Digest, Vol. 38, No. 1, Jan., 1941, p. 160.)
29195 Germany	*Large Series Production of Aircraft by the "Rhythm" Method at Junkers Works.* (W. Schnizler, Z.V.D.I., Vol. 85, No. 37-38, 20th Sept., 1941, pp. 781-784.)
29278 U.S.A.	*Production of Martin B. 26 Medium Bombers.* (H. F. Kniescha, Aero. Digest, Vol. 38, No. 4, April, 1941, pp. 133-134 and 193.)

R.T.P. Ref.	*Title and Journal*
	Assembly Methods—*continued*
29595 Germany	*Mass Production of Aircraft by the Rhythm or "Timed Flow" Method.* (H. Mullenbach, Luftwissen, Vol. 8, No. 9, Sept., 1941, pp. 286-289.)
479 Gt. Britain	*Handley Page Halifax.* (Airc. Eng., Vol. 14, No. 155, Jan., 1942, pp. 12-13 and 15.)
482 Gt. Britain	*Avro Manchester.* (Airc. Eng., Vol. 14, No. 155, Jan., 1942, pp. 16-17.)
539 Gt. Britain	*Short Stirling Heavy Bomber.* (The Engineer, Vol. 173, No. 4490, 30th Jan., 1942, pp. 95-97.)
558 Gt. Britain	*Short Stirling Bomber.* (Flight, Vol. 41, No. 1727, 29th Jan., 1942, pp. 94-109 and 86.)
977 Gt. Britain	*Boulton Paul Defiant.* (Engineer, Vol. 173, No. 4493, 20th Feb., 1942, pp. 156-158.)
1146 Gt. Britain	*Beaufighter II.* (Aeroplane, Vol. 62, No. 1605, 27th Feb., 1942, pp. 230-231.)
1153 Gt. Britain	*The Short Stirling.* (Aeroplane, Vol. 62, No. 1605, 27th Feb., 1942, pp. 239-242.)
1955 Gt. Britain	*Handley Page Halifax II.* (Aeroplane, Vol. 6, No. 1613, 24th April, 1942, pp. 465-470.)
1959 Gt. Britain	*Handley Page Halifax.* (Engineer, Vol. 173, No. 4502, 24th April, 1942, pp. 344-346.)
2024 Gt. Britain	*Bristol Beaufighter.* (Aeroplane, Vol. 62, No. 1612, 17th April, 1942, p. 437.)
2026 Gt. Britain	*British Transport Aircraft for Communication.* (Aeroplane, Vol. 62, No. 1612, 17th April, 1942, pp. 440-41.)
2039 Gt. Britain	*The Halifax Heavy Bomber.* (Flight, Vo. 41, No. 1739, 23rd April, 1942, pp. 398-405.)
2187 Gt. Britain	*Handley Page Halifax II.* (Engineer, Vol. 173, No. 4503, 1st May, 1942, pp. 364-366.)
2192 Gt. Britain	*Handley Page Halifax.* (Engineering, Vol. 153, No. 3981, 1st May, 1942, pp. 347-348 and 350.)
2905 Gt. Britain	*Directional Flow Production.* (Airc. Prod., Vol. 4, No. 40, Feb., 1942, pp. 200-204.)
3078 U.S.A.	*Automatic Technique Used in Plane Production.* (J. Geschelin, J.S.A.E., Vol. 50, No. 5, May, 1942, p. 45.)
3157 Gt. Britain	*Large scale Production of the Bell Airacobra.* (Airc. Prod., Vol. 4, No. 42, April, 1942, p. 283.)
3158 Gt. Britain	*The Spitfire in Production.* (W. E. Goff, Airc. Prod., Vol. 4, No. 42, April, 1942, pp. 284-294.)
3159 Gt. Britain	*Douglas Line Assembly.* (Airc. Prod., Vol. 4, No. 42, April, 1942, p. 297)
3166 Gt. Britain	*The Spitfire in Production.* (W. E. Goff, Airc. Prod., Vol. 4, No. 43, May, 1942, pp. 332-342.)

R.T.P. Ref.	Title and Journal
	ENGINES
26021 U.S.A.	*Aero-Motors Supplied by the U.S.A. to Gt. Britain.* (Aeroplane, Vol. 60, No. 1547, 17th Jan., 1941, pp. 98-100.)
80 Gt. Britain	*The Bristol Hercules.* (Flight, Vol. 40, No. 1718, 27th Nov., 1941, G. G. Smith, pp. 379-383.)
81 Gt. Britain	*Barrel Engines.* (Flight, Vol. 40, No. 1718, 27th Nov., 1941, E. S. Hall, pp. 386-389.)
3499 Gt. Britain	*Torque on Engine Mountings.* (C. D. Graham and N. R. Tembe, Airc. Eng., Vol. 14, No. 160, June, 1942, pp. 162-163.)

281

PRACTICAL EXAMPLES OF AERO ENGINE SUPERCHARGERS

(W. von der Null, Z.V.D.I., Vol. 85, No. 47/48, 29th Nov., 1941, pp. 965/913)

Centrifugal supercharger installations for the following engines are described in some detail engines :--

(1) Hirth H.M. 508C (270 h.p. 8-cylinder V. aircooled).
(2) Rolls Royce Merlin.
(3) Hispano Suiza 127.
(4) Junkers 210.
(5) Bristol Pegasus and Hercules.
(6) Wright Cyclone.

Some reference is also made to the D.V.L. supercharger and 2-speed gear, the Hispano-Suiza 9-stage axial blower and a proposed combined axial-centrifugal supercharger. Of interest are test results obtained by the D.V.L. on a Merlin II and Hispano supercharge respectively.

In spite of the higher theoretical efficiency of the axial type of compressor, the very steep characteristic of this design is a serious drawback in engine supercharging. The need for maintaining small blade tip clearance over a relatively long casing also presents great difficulties, since at least nine impellers have to be accommodated on one shaft in order to produce the necessary pressure head.

According to the author, the axial type of supercharger is only of interest to high altitudes when type acting as the first stage of a centrifugal blower. At such very low intake densities, it is difficult to obtain a sufficient entry area without a considerable increase in the rotor diameter of the purely centrifugal type. The axial type does not suffer from this trouble to the same extent and by supplying a compressed charge to the centrifugal blower, the overall diameter of the combination can be considerably reduced.

1017

STEAM POWER PLANTS FOR AIRCRAFT

(E. Knornschild, Luftwissen, Vol. 8, No. 12, Dec., 1941, pp. 366-373)

The idea of a central steam generating plant operating a number of turbines distributed along the wing and driving individual propellers is so tempting for large aircraft necessitating 10,000 h.p., or more, that the problem has frequently been investigated. The fundamental difficulty in such installations is the condenser, which has to deal with about four times the heat flow of an i.c. engine of equivalent output. At the same time the steam must be condensed entirely by air cooling and the heat transfer coefficients under these conditions are low. It appears certain that the available wing area will not suffice to house a surface condenser of sufficient size and the author suggests that a tunnel installation inside the fuselage operating in conjunction with a blower offers a chance of some of the waste heat being utilised for propulsion.

If the condenser problem could be solved, reasonable specific weights for turbine and boiler should be possible, although the specific fuel consumption is bound to be higher than that of the i.c. engine because a high vacuum cannot be maintained in the condenser.

In this connection the rotary boilers of Huttner and Vorkauf (Germany) and Bechard (France) are of interest.

The basic feature of these machines are described by the author, who also gives some details of experiments carried out in the U.S.A. by the Great Lakes Aircraft Corporation and the G.E.C.

It appears likely that boilers of the Velox type, with supercharged combustion and forced circulation, will be the most suitable for aircraft installation. In this connection the 1,600 h.p. turbine installation on a German coastal patrol boat are of interest. It is stated that this power plant has a specific weight of about 10 kg./h.p. at a fuel combustion of 310 gm./h.p. hour.

A useful bibliography of twenty-three items concludes the article, which is well illustrated (fifteen figures).

25071

RECENT DEVELOPMENTS IN PROPELLER BLADE DESIGN

(L. H. Enos, Aero. Digest, Vol. 37, No. 2, Aug., 1940, pp. 48-51).

During the past year, means of reducing propeller blade weight have been given considerable attention. The lower weight of hollow welded steel blades as compared to the 25S aluminium alloy blades has led to the development of a new aluminium alloy with higher strength characteristics.

The characteristics of this new alloy (X76S) are given below :—

Table I

	25S	X76S
Ultimate strength (p.s.i.)	58,000	73,000
Yield point (p.s.i.)	38,750	65,000
Reduction of area (%)	31-38	35
Elongation (%)	16	15
Brinell	100	147
Fatigue smooth specimen (p.s.i.)	15,000	20,000
Specific gravity	2.79	2.79
Fatigue stress sp. gr.	5,380	7,170

From the increased allowable fatigue stress of the X76S alloy as compared to the 25S, it would at first appear that a large reduction in weight can be made. There are certain features of design, however, which restrict taking the fullest possible advantage of this improvement, and the hollow steel propeller is still appreciably lighter.

During the past year improvements in manufacture and design of hollow steel blades have been achieved.

Since the Curtiss hollow steel blade is made up of two sections welded together it is necessary that the steel possess desirable welding characteristics. The welding process used is the atomic hydrogen process which gives a high strength uniform weld. Physical characteristics of the steel used for both virgin and welded portions are given in Table II.

Table II

	Virgin Stock	Weld Stock
Ultimate tensile strength (p.s.i.)	145,000	115,000
Yield point (p.s.i)	131,000	109,000
Reduction of area (%)	59	50
Elongation (%)	14	10
Rockwell "C"	31	21
Fatigue smooth specimen (p.s.i.)	83,000	60,000
Specific gravity	7.9	7.9
Fatigue stress sp. gr.	10,500	7,600

A further advantage of the hollow steel propeller lies in the fact that blade shank fairings or cuffs can be easily fitted.

With aircraft engines giving increasing powers and with the stringent requirements as to allowable cylinder temperature, better cooling from the propeller has become necessary. Cuffs have assisted greatly in the problem of using the increased engine powers without additional cowl opening or increasing the size of the cowl flaps. Designers who have seen the results of cuffs on their installations are taking advantage of the improvement by fitting the smallest possible cowl. On one typical single engine installation the addition of cuffs to the propeller which was fitted with a fair-sized spinner resulted in the following average reduction of temperature, on the ground: cylinder head 40° C., cylinder base 10° C., the spark plug elbows 16° C. During climb the reduction was much less, and at V max. no difference was noted. Because of the smaller cowl possible with cuffs the V max. was increased 1%, which was equivalent to 25 thrust h.p. The cuff installation weighed 10 lbs.

25187

COUNTER ROTATING AIRSCREWS

(H M. McCoy, Inter. Avia., No. 721, 6th Aug., 1940, pp. 1-4)

Counter rotating airscrews have so far been utilised on fixed-wing machines in three different versions.

(1) Twin engined aircraft with tractor airscrews rotating in opposite directions.

(2) Combination of pusher and tractor airscrews at opposite ends of the engine power plant (usually two engines placed back to back—so-called open tandem spacing).

(3) Two oppositely rotating airscrews placed immediately one behind the other on concentric shafts (close tandem).

A machine fitted with airscrews rotating in opposite directions is freed from torque reaction and in addition there is generally an improvement in longitudinal stability.* At high flying speeds, moreover, the close tandem arrangement may produce an appreciable increase in propulsive efficiency by reducing the rotary slip stream losses. As is well known, such losses only become appreciable at high blade angles (i.e., high flying speeds) and below 350 m.p.h. (i.e., for blade angles $< 45°$) the predominant slip stream losses are axial.

Tests on a Curtiss P-36 fighter fitted with close tandem airscrew showeds a marked improvement in control. Improvement in performance was not shown nor expected, since the flight speeds were too low. A remarkable freedom from engine vibrations was specially noted. It is confidently stated that higher flight speeds in the future will lead to a more general introduction of the close tandem arrangement. Some of the further advantages claimed are listed below :—

(1) Reduction of span of fast single-engined fighters (lighter wing and greater structural efficiency).

(2) Decreased turbulence in slip stream delays separation of boundary layer.

(3) Vertical fin need not be offset.

Disadvantages are weight and cost of gearing.

* See M.A.P. Translation No. 853.

R.T.P. Ref.	*Title and Journal*
	POWER EGGS AND ENGINE MOUNTINGS
216 Gt. Britain	*Electric v. Hydraulic Auxiliary Drives and Starters.* (Flight, Vol. 41, No. 1724, 8th Jan., 1942, p.f.)
3318 Germany	*Modern Power Plant Installations (Junkers.)* (Flugwehr und Technik, Vol. 4, No. 5, May, 1942, pp. 124-25.)
3319 France	*French Views on Power Plant Problems (Tandem Engines).* (C. Waseiger, Inter. Avia., No. 822, 26th June, 1942, pp. 17-18.)
3435 U.S.A.	*Ground v. Flight Test of Aeroplane Power Plants.* (J. B. Kendrick; S.A.E.J., Vol. 50, No. 6, June, 1942, pp. 241-251.)
	PROPELLERS
25621 Gt. Britain	*Rotol Airscrew De-Icing Equipment.* (Flight, Vol. 38, No. 1665, 21st Nov., 1940, p.f.)
25874 Gt. Britain	*Feathering Airscrews.* (L. B. Greensted, Aeroplane, Vol. 59, No. 1543, p. 711.)
26260 Germany	*The Junkers V.P. Airscrew.* (Airc. Eng., Vol. 13, No. 144, Feb., 1941, pp. 33-4 and 37.)
26444 Switzerland	*Escher-Wyss Variable Pitch Propeller—Constructional Principles.* (A. von der Mühll, Flugwehr und Technik, Vol. 2, No. 11-12, Nov.-Dec., 1940, pp. 258-60.)
28284 Gt. Britain	*Rotol Contra-rotating Airscrew.* (Flight, Vol. 40, No. 1704, 21st Aug., 1941, pp. d/e.)

R.T.P. Ref.	*Title and Journal*
	Propellers—*continued*
28450 Gt. Britain	*The Contra-Prop.* (Aeroplane, Vol. 61, No. 1578, 22nd Aug., 1941, p. 211.)
28544 U.S.A.	*Fairey Contra-rotating Airscrew.* (Flight, Vol. 40, No. 1706, 4th Sept., 1941, p. 133.)
5 Gt. Britain	*Rotol Jablo Wood Airscrew Blades.* (W. Brierly, Aeroplane, Vol. 61, No. 1596, pp. 704-705, Dec., 1941.)
1090 Gt. Britain	*Rotol Contra-rotating Airscrew.* (Airc. Eng., Vol. 14, No. 156, Feb., 1942, p. 42.)

29140

TANDEM AIR PROPELLERS

(E. P. LESLEY, N.A.C.A., Tech. Note, No. 822, Aug., 1941, pp. 1-11)

Tests of three-blade, adjustable-pitch counter-rotating tandem model propellers, adjusted to absorb equal power at maximum efficiency of the combination, were made at Stanford University.

The aerodynamic characteristics, for blade-angle settings of 15°, 25°, 35°, 45°, 55°, and 65° at 0.75R of the forward propeller and for diameter spacings of 8½, 15, and 30% were compared with those of three-blade and six-blade propellers of the same blade form.

It was found that, in order to realise the condition of equal power at maximum efficiency, the blade angles for the rear propeller must be generally less than that for the forward propeller, the difference increasing with blade angle.

The tests showed that, at maximum efficiency, the tandem propellers absorb about double the power of three-blade propellers and about 8% more power than six-blade propellers having the pitch of the forward propeller of the tandem combination.

The maximum efficiency of the tandem propellers was found to be from 2 to 15% greater than for six-blade propellers, the difference varying directly with blade angle. It was also found that the maximum efficiency of the tandem propellers was greater than that of a three-blade propeller for blade angles at 0.75R of 25° or more. The difference in maximum efficiency again varied directly with blade angle, being about 9% for 65° at 0.75R.

R.T.P. Ref.	*Title and Journal*
	RADIATORS AND HEADER TANKS
26426 U.S.A.	*Propulsive Effects of Radiator and Exhaust Ducting.* (Rauscher and W. H. Phillips, J. Aeron. Sci., Vol. 8, No. 4, Feb., 1941, pp. 167-74.)

889

AIRCRAFT FUEL SYSTEMS

(F. W. HECKERT, S.A.E. Journal, Vol. 50, No. 1, January, 1942, p. 23) (Digest)

Fuel tanks should have their outlet lines covered in all normal flight operations. Proper vents must be fixed and hydraulic losses, especially on the suction side, reduced to an absolute minimum.

Traps in the fuel line system must be as few as possible and all necessary connections should be mounted so that they are free from vibration.

The primary difficulty is the avoidance of vapour lock. Most existing systems have their pumps located below the hydraulic gradient and vapour lock may occur at high altitudes. The author describes an electric-driven centrifugal pump which automatically vents the vapour and which, placed in front of the engine-driven pump, feeds the latter with vapour-free liquid at a pressure in excess of that of the outer atmosphere. In addition to thus solving vapour lock troubles, the booster system has the following additional advantages:—

(1) Standard engine-driven fuel pumps can be retained.
(2) Starting up is facilitated.
(3) In case of engine pump failure, the booster can maintain supply and take the place of the handpump.
(4) The booster can be employed for transfer of fuel from one tank to another.

29161

A NEW HIGH-ALTITUDE FUEL SYSTEM FOR AIRCRAFT

(W. H. CURTIS and R. R. CURTISS, J.S.A.E., Vol. 49, No. 1, July, 1941, pp. 260-265)

This paper deals in a general way with a brief history of the work that has been done in the past on aircraft fuel systems to adapt them for high-altitude flight, the reasons for failures that developed, some of the physical aspects of aircraft fuel at high altitude, and a brief description of the Thompson Booster system.

The Thompson Booster system was evolved as the result of the application of analytical reasoning to the fuel systems that preceded it. The booster unit is a modified centrifugal pump, attached directly to the fuel tank and driven by an electric motor. Its function is to prevent entrance of released vapour and air to the fuel line leading to the fuel pump on the engine. It also maintains sufficient pressure in this line to prevent additional release of air vapour.

27846 and 27847

SOME PECULIARITIES IN THE WORKING OF AIRCRAFT FUEL SYSTEMS

(G. K. VOLKOV, Air Fleet News, U.S.S.R., Vol. 23, No. 5, pp. 442-4)

OPERATION OF AIRCRAFT FUEL SYSTEMS AT HIGH ALTITUDES

(M. P. FOKINE, Air Fleet News, U.S.S.R., Vol. 23, No. 5, pp. 445-7)

Both articles deal with the problem of vapour locks in fuel systems, giving rise to irregular running, especially at altitude.

After discussing the conditions of occurrence of vapour locks, with particular reference to the influence of accelerations in unsteady flight, the requirement is set up that the fuel system should be previously checked for correct operation under all likely conditions of flight.

The second article deals more particularly with experiments made by P. A. Rybakov on the causes of uneven running at altitude, which was found to be due principally to vapour locks in the fuel system.

The conclusion is arrived at, that vapour locks at altitude are caused principally by excessively high temperature of the fuel as taken in on the ground, in conjunction with the relative vapour tension of the fuel. Fuel grades of a vapour tension between 270 and 330 mm.-mercury at 38° C. are considered safe from vapour lock at normal altitudes of present-day flight. It is, however, necessary to ensure that the fuel is not excessively heated while stored on the ground.

27847 OPERATION OF AIRCRAFT FUEL SYSTEM AT HIGH ALTITUDES

(M. P. FOKINE, Air Fleet News, U.S.S.R., Vol. 23, No. 5, May, 1941, pp. 445-7)

Irregularities in the running of aircraft engines at high altitudes are due to the formation of " vapour locks " in the fuel system.

Such " vapour locks " are produced by :—

(1) Presence of high-volatility components in the fuel, which separate at high altitudes owing to the reduced atmospheric pressure.

(2) Pressure of dissolved air in the fuel, which segregates under the same conditions.

(3) Heating of the fuel in certain parts of the system, promoting volatilisation of the fuel.

The proportion of high volatile fractions in the petrol can be determined by the vapour tension, the normal figure being 360 mm. Hg. at 38° C. The higher the tension, the greater the risk of " vapour locks."

The fuel should therefore be kept as cool as possible in ground storage and protected both there and in the fuel tanks from the heat of the sun. A vapour tension of 270-330 mm. Hg. at 38° C. should ensure normal running at altitude.

R.T.P. Ref.	*Title and Journal*
	UNDERCARRIAGE
25952 Gt. Britain	*Undercarriages.* (R. Hadekel, Aeroplane, Vol. 59, No. 1545, pp. 23-26.)
26102 Germany	*Tricycle Undercarriages.* (W. Wernitz, Luftwissen, Vol. 7, No. 3, March, 1940, pp. 73-82.) (Airc. Eng., Vol. 13, No. 143, Jan., 1941, p. 6-12.)
3175 Gt. Britain	*Landing Gear Components on the Halifax.* (Airc. Prod., Vol. 4, No. 44, pp. 379-382, June, 1942.)

4511

TRICYCLE LANDING GEAR DESIGN (Part I)

(E. S. Jenkins and A. F. Donovan, J. Aeron. Sci., Vol. 9, No. 10, August, 1942, pp. 385-396)

The problems of the tricycle landing gear are discussed in the light of available information with the object of providing criteria to assist the designer. The general geometric arrangement involving the determination of wheel base, tread, and centre of gravity location is first considered. It is shown that the nose wheel should be located as far forward of the centre of gravity as possible, and that the fore-and-aft location of the rear wheels is limited to a narrow range by conditions of balance and longitudinal stability. The relationship between tread, wheel base, and the resistance to turning over is found, and the effects of tread and for-and-aft location of the rear wheels on the directional stability and ground manœuvreability are discussed.

The problems related specifically to the design of the nose wheel are next examined, and a basis for the selection of nose wheel and tyre size is given. The fundamental causes of shimmy are reviewed, including the effects of trail, caster angle, wheel offset, tyre, and moment of inertia of castering parts. Shimmy elimination is discussed with special reference to elimination by damping and including methods of calculating the amount of damping necessary to prevent shimmy. The construction of fluid dampeners is described, and their damping characteristics are compared to the simpler mathematically defined types of damping. An empirical relationship between the volume of a vane-type hydraulic dampener necessary to prevent shimmy and the static nose wheel load is given.

Ground handling and manœuvreability, construction and installation difficulties, castering locks and stops, and steering devices are briefly discussed. Conclusions as to the best arrangements must be based on the characteristics of the particular design. As a partial check on the validity of the criteria developed, the results of applying them to some successful tricycle gear aeroplanes are summarised.

5490

TRICYCLE LANDING GEAR DESIGN (Part II)

(E. S. Jenkins and A. F. Donovan, J. Aeron. Science, Vol. 9, No. 11, Sept., 1942, pp. 397-410)

Principal Conclusions

Effects of Wheel Base

(1) Increase in the distance of the nose wheel forward of the c.g. rapidly reduces the critical design loads on the nose wheel, decreases the probability of pitching oscillations, and increases the resistance of the aeroplane to turning over.

(2) The distance of the rear wheels aft of the c.g. must be sufficient so that the c.g. will be forward of the rear wheels with the aeroplane in the tail-down attitude. At the same time, the distance aft of the wing aerodynamic centre should not exceed the maximum value at which the aeroplane will be longitudinally stable when taxi-ing on only the rear wheels at take-off speeds.

(3) An increase in the distance of the rear wheels aft of the c.g. also results in increased directional stability, a small reduction in the resistance to overturning, and a reduced likelihood of pitching oscillations during taxi-ing on all three wheels.

Effects of Tread

Satisfactory ratios between the values of wheel base and tread are best obtained by careful application of the criteria and cannot be arbitrarily defined.

Effects of Caster Angle

(1) Positive caster angle increases the tendency to shimmy and requires additional damping.

(2) Negative caster angles up to about 8° decrease the tendency to shimmy.

(3) For zero caster angle the nose wheel neither centres nor turns crosswise when stopped but remains pointed in the direction in which it was last rolling.

(4) From the standpoint of handling characteristics and damping requirements, a zero caster angle is preferable. Structural requirements may, however, necessitate the use of a positive caster angle.

Effects of Trail

(1) The trail must be positive at all times, at all possible angles of yaw of the nose wheel, and at all encounters of the nose wheel with obstructions.

Effects of Tyre

All rubber-tyred castering wheels will shimmy unless equipped with a damping device or other means of shimmy prevention.

Effects of Moment of Inertia of Castering Parts

(1) The viscous damping necessary increases with the moment of inertia of the castering parts.

(2) The solid friction damping required is independent of the moment of inertia of the castering parts.

Effects of Type of Damping Used to Prevent Shimmy

(1) Solid friction damping makes steering and ground handling too difficult to be satisfactory except on very small aeroplanes.

(2) Fluid dampener size is apparently controlled not by the smallest dampener that can prevent shimmy but by the smallest dampener capable of providing the necessary damping, together with a small enough resistance at low angular velocities to produce satisfactory steering characteristics.

(3) The amount of any particular type or combination of types of damping necessary to prevent shimmy in a particular installation may be approximated mathematically.

27604

THE NOSE WHEEL LANDING GEAR

(Inter. Avia., No. 715, 24th April, 1941, pp. 1-5)

The employment of landing flaps required the pilots to abandon their earlier landing techniques. The approach glide for the landing had now to be made with the longitudinal axis of the aircraft in a more or less forward-inclined position, and the change in the angle during flattening out and stall was doubled. The logical thing was, therefore, to develop a landing gear in which the final position of the aeroplane on the ground corresponded more closely to the landing inclination. Thus, the way was paved for the nose-wheel landing gear, and to-day practically all new commerical and military aircraft produced in the United States are fitted with the nose wheel.

Since in the tricycle undercarriage the nose wheel is mounted far in front of the centre of gravity, the danger of a nose-over is completely eliminated, and full brake power can be applied immediately after touching down, as a result of which the approach glide for the landing need not necessarily be made at the minimum speed, and the dependency of the landing distance on the gliding speed is reduced. If a downward motion still exists when touching down, it will not result in the aircraft jumping off again, no matter whether the nose wheel or the main wheels touch down first, as on the one hand the location of the centre of gravity equally favours the touching down of all three wheels and, on the other hand, the wing has a smaller angle of incidence in the taxi-ing position than in the glide. Even when the tricycle aeroplane is flattened out at a great angle of incidence, the touching down of the main wheels immediately causes the nose wheel to touch down also and, thus, a decrease of the angle of incidence results. In drift landings or crosswind landings, the brake power of the main wheels creates a stabilising moment which maintains the aeroplane's longitudinal axis in the landing direction, so that also in this case the danger of a lateral tip-over or a turning away from the landing direction is avoided.

Additional advantages of the nose wheel undercarriage are: Considerably improved vision for the pilot during take-off, landing and taxi-ing; simplified start, as the aeroplane assumes the position offering the smallest frontal area, and the longitudinal axis of the aeroplane must not first be brought into the horizontal position by movements of the control column; finally, increased comfort for the passengers of commercial airliners due to the fact that the position of the longitudinal axis of the fuselage is practically constant during take-off and landing and in level flight.

The main disadvantage of the nose wheel landing gear is an increase in the gross weight. This is explained by the fact that the main wheels must be designed for loads at least equal to those for which the main wheels of the conventional undercarriage are built. Even to-day no generally valid load data for the calculation of the tricycle landing gear are available; in any case, however, the possibility of higher landing and taxi-ing speeds requires more rugged and therefore heavier designs. The major portion of the weight increase is furnished by the nose wheel itself, which must be

capable of withstanding the heavy loads resulting from the sudden braking of the main wheels and must be connected with the rudder control. This requires a strengthening of the fuselage nose, which ultimately results in an increase of the weight of the entire tricycle installation by 50% over that of the tail-wheel landing gear.

It is quite possible that the universal adoption of the nose wheel landing gear will profoundly affect the design of new types, inasmuch as it will be attempted to free the nose for the nose wheel by shifting the power plant to the centre portion of the fuselage or by substituting pusher designs. It would appear that considerations of this kind have strongly influenced the development of the Bell P-39 "Airacobra" fighter, all the more as the unobstructed space in the fuselage nose was required also for the armament installation.

A disagreeable feature of the tricycle landing gear is formed by the shimmying tendency of the steerable nose wheel, discernible at certain speeds both at take-off and on landing.

Exhaustive tests conducted by the N.A.C.A. are ample proof that an improvement of these detrimental features is being sought also in the United States. The main difficulty of the problem appears to lie in the fact that the nose wheel shimmy should be eliminated without impairing the steerability of the wheel. The tests have shown that the effect of the type of tyre pressure is negligible, that the caster angle and spindle moment of inertia influence the damping force in the first instance, and that solely by solid friction damping the shimmy nose of wheels of big aeroplanes cannot be prevented.

Everything considered, the advantages of the nose wheel landing gear appear far to outweigh the disadvantages. The main improvement, which coincides with the general trend towards higher wing loadings, is indicated by the possibility to land aeroplanes at speeds in excess of the minimum flying speed without requiring any considerable lengthening of the landing run.

R.T.P. Ref.

TYRES

6280 U.S.A. — *Firestone Conductor Tyres Discharge Static Electricity.* (Aviation, Vol. 40, No. 1, Jan., 1941, p. 70.)

29844 U.S.A. — *New Rayon Tyre for D.C.3 Transports.* (American Aviation, Vol. 5, No. 10, 15th Oct., 1941, p. 43.)

30051

TYRE PROFILE

(Inter. Avia., No. 782, 24th Sept., 1941, p. 15)

By providing new shapes for the tyres of main and nose wheels of aeroplanes, the Firestone Tyre and Rubber Co., of Akron, O., is seeking to cope with the continuously increasing wheel pressures of modern fighter aeroplanes. In order to facilitate take-offs and landings on soft airport surfaces, the company has developed tyre profiles characterised by completely flat treads which even have projecting rims on both sides. By this means the whole tread of the tyre comes into contact with the soil without the wheel digging excessively into the soft ground; this design also prevents the occurrence of side-slipping. For nose wheels the Firestone Company also proposes tyres with similarly flat profiles which, in addition, are pressed together laterally by extraordinarily wide rim flanges, as a result of which the wheel does not jam the fork even when insufficiently inflated.

R.T.P. Ref.

HYDRAULICS

25630 Gt. Britain — *Hydraulic Servo Mechanisms.* (L. Pomeroy, Jr., Aeroplane, Vol. 59, No. 1539, 22nd Nov., 1940, pp. 577-580.)

29435 U.S.A. — *Aeroplane Hydraulic Systems.* (E. M. Breen, Aviation, Vol. 40, No. 9, Sept., 1941, pp. 70-71, 152-156 and 162.)

2265 U.S.A. — *Hydraulic System Installations (Part III) (Control and Actuating Circuits).* (J. E. Thompson and R. B. Campbell, Aero. Digest, Vol. 40, No. 1, Jan., 1942, pp. 136-145 and 248.)

2623
THE GROWTH AND DEVELOPMENT OF AIRCRAFT HYDRAULIC SYSTEM AND EQUIPMENT

(H. J. Marx, S.A.E.J., Vol. 50, No. 4, April, 1942, p. 35)

According to the authors any system for operating landing gear, flaps and brake must meet the following requirements :—

(1) Light weight.
(2) Reliable and not vulnerable.
(3) Compact and small power loss in transmission.
(4) Semi-skilled installation and maintenance.
(5) Low cost.
(6) Capable of storing energy for emergency use.

Compressed air or vacuum operation has not been found to be reliable. This leaves the choice between hydraulic and electrical systems. It appears that there is a definite field of application for each type, the hydraulic being best adapted to variable speed control and the application of large forces.

A drawback of the hydraulic system is its greater vulnerability in aerial combat (bullets puncturing oil lines have caused fires), whilst operating at very low temperatures (i.e., below 60° F.) is also likely to be difficult due to the absence of suitable liquids.

29142
STANDARDISATION OF LIQUIDS EMPLOYED IN HYDRAULIC CONTROLS AND SHOCK ABSORBERS OF AIRCRAFT

(V. Ceccarini, Atti di Guidonia, No. 39-40, 10th Dec., 1940)

After a reference to the urgent need of standardising the liquids employed for shock absorbers and hydraulic systems on aircraft, the author gives the characteristics of the most important existing liquids and then considers castor oil + diacetone alcohol mixtures, which, of the liquids in use, appear to be of the greatest interest.

Three mixtures of castor oil and diacetone alcohol prepared in the laboratory for jacks, oleo-pneumatic and oleo-elastic shock absorbers were examined. Descriptions are given of the chemical and physical tests carried out on these mixtures in order to ascertain their behaviour under service conditions. A method for the determination of their action on the metals and the rubber used in the fittings is described. The results are discussed also with respect to the possibilities of employing mineral oils, the other highly important group of liquids and perhaps the only ones which may present real advantages over the castor oil-diacetone mixtures.

A scheme of standardisation for the mixtures is suggested.

In conclusion, the relative merits of the two possible solutions, namely the castor oil + diacetone alcohol mixtures and mineral oils are compared ; the latter are found to be more advantageous, provided suitable viscosity characteristics can be obtained (? doping) and that only synthetic rubber connections are employed.

PIPING

R.T.P. Ref.	
26279 U.S.A.	*Simplifying Aeroplane Maintenance : Self-sealing Coupling makes Possible Faster Exchange of Aircraft Power Units.* (F. P. Hirsch, Aviation, Vol. 40, No. 1, Jan., 1941, p. 69.)
29436 U.S.A.	" *Cerrobend* " (*Bismuth Alloy Filler for Making Tube Bends*). (D. J. G. Rowe, Aviation, Vol. 40, No. 9, Sept., 1941, pp. 74-75 and 174.)
867 U.S.A.	*Bullet Proof Fuel Hose.* (Aero. Digest, Vol. 39, No. 6, Dec., 1941, p. 248.)
1752 Gt. Britain	*Precision Pipe Bending* (I). (Engineer, Vol. 173, No. 4499, 3rd April, 1942, pp. 292-293.)
1840 Gt. Britain	*Precision Pipe Bending* (II). (Engineer, Vol. 173, No. 4500, 10th April, 1942, pp. 312-315.)
3087 Gt. Britain	*Precision Pipe Bending.* (Airc. Prod., Vol. 4, No. 43, pp. 363-366, May, 1942.)

R.T.P. Ref.	**Piping**—*continued*
3161 Gt. Britain	*Tube Bending (a Simple Method).* (Airc. Prod., Vol. 4, No. 42, p. 310, April, 1942.)
3214 Gt. Britain	*Precision Pipe Bending.* (Engineer, Vol. 174, No. 4513, p. 40, 10th July, 1942.)
3894 Gt. Britain	*Precision Press-Bending of Pipes.* (Engineering, Vol. 154, No. 3391, 10th July, 1942, p. 36.)

R.T.P. Ref.	*Title and Journal* **ELECTRICS**
26211 Gt. Britain	*Aeroplane Landing Lights.* (Aeroplane, Vol. 59, No. 1550, 7th Feb., 1941, pp. 179-81.)
26373 U.S.A.	*Applications of Electric Power in Aircraft.* (T. B. Holliday, Autom. Ind., Vol. 84, No. 4, 15th Feb., 1941, pp. 164, 188.)
26841 Gt. Britain	*Electric Hydraulic Equipment for Aircraft.* (Science Library Bibliography No. 554.)
28867 Gt. Britain	*Electric Power in Aircraft (I).* T. B. Holliday, Aeroplane, Vol. 61, No. 1585, 10th Oct., 1941, pp. 404-405.)
28921 Gt. Britain	*Electric Power in Aircraft.* (T. B. Holliday, Aeroplane, Vol. 61, No. 1586, 17th Oct., 1941, pp. 433-434.)
29032 U.S.A.	*Electric Power on Aircraft.* (W. H. Fromm, Aviation, Vol. 40, No. 7, July, 1941, pp. 52 and 150.)
29324 Gt. Britain	*Electric Power in Aircraft, Part III.* (T. B. Holliday, Aeroplane, Vol. 61, No. 1587, 24th Oct., 1941, pp. 454-455.)
29907 U.S.A.	*Electrical Equipment on Aircraft.* (Aero. Digest, Vol. 37, No. 5, Nov., 1940, pp. 137-138.)
200 Gt. Britain	*Aircraft Electrical Wiring, Part I (with Special Reference to the Breeze Method).* (Airc. Prod., Vol. 4, No. 39, Jan., 1942, pp. 119-120.)
2903 Gt. Britain	*Aircraft Electrical Wiring, Part II.* (Airc. Prod., Vol. 4, No. 40, Feb., 1942, pp. 187-189.)
1020 Germany	*Aircraft Lighting (Position Lights, Landing, Searchlight, Cabin and Instrument Lights).* (G. Reisberg and E. Rasler, Luftwissen, Vol. 8, No. 12, Dec., 1941, pp. 380-389.)
1277 Gt. Britain	*Aircraft Electrical Wiring, Part III (Installation and Maintenance of the Breeze System—Wiring and Layout Diagrams).* (Airc. Prod., Vol. 4, No. 41, March, 1942, pp. 234-236.)
2533 U.S.A.	*Electrical Power in Aircraft.* (G. W. Ledbetter, Aero. Digest, Vol. 40, No. 2, Feb., 1942, pp. 163-70.)
871 U.S.A.	*Synthetic Flexible Electric Conduit.* (Aero. Digest, Vol. 39, No. 6, Dec., 1941, p. 255.)
3610 U.S.A.	*Wiring for Aircraft.* (Lester C. Jones, Lockheed Aircraft Corporation, Paper No. 59.)

1020

AIRCRAFT LIGHTING (NAVIGATION AND LANDING, COCKPIT AND INSTRUMENT)

(G. Reisberg and E. Rosler, Luftwissen, Vol. 8, No. 12, Dec., 1941, pp. 380-384)

The usual voltage of aircraft electric circuits is either 12 or 24. With the generator in action (battery charging) the voltage generally rises to 14 or 29 volts, and the lamps operating under these conditions must be designed accordingly. Lamps, such as the landing searchlight, which operate on the battery only (generator out of action), must operate on the lower voltage.

Aircraft lamps are subjected to considerable vibration, not only during landing and take-off (rough ground) but also in the air. At the same time (and this applies especially to external lights such as navigation and searchlights) the lamps must be as small as possible so that the air-drag can be kept to a minimum. Position lights are rated between 5 and 25 watts, whilst the searchlights go up to 500 watts. The lamps for cockpit and instrument lighting vary between 2 and 15 watts.

The authors describe typical lamps used for these various purposes (Osram), references being also made to fluorescent lighting by means of ultra-violet lamps. Till quite recently such mercury vapour lamps required alternating voltage of at least 220 volts. The new Osram lamp however functions on 12 v. (D.C.).

Whilst the illumination for the pilot and his instruments may be considered adequate, the authors stress the fact that the amount of light available for the rest of the cabin is inadequate and this applies especially to civil aircraft. Improvements are scarcely possible until the amount of electrical power available on aircraft is increased considerably over present-day standards.

29683

CABLE WEIGHTS OF ELECTRICAL INSTALLATION IN AIRCRAFT

(E. Ruhlemann, Flughafen, Vol. 9, No. 4, April, 1941, pp. 3-5)

Details of the electric cable system on a Dornier aircraft (unspecified) are given. The cables range from multistrand (5mm.² cross-section of each wire) to single wires of 25mm.² cross-section. On a basis of actual length of wire used (i.e., in case of multistrand, length of cable X number of strands) the smaller cross-sections up to 1.5mm.² account for over 90% of the total length installed. Of this 90%, 66% are accounted for by wires of .75mm.² cross-section. On a weight basis, however, sections up to 1.5mm.² only account for 60% of the total, the remaining 40% being made up by sections of 2.5mm.² and above. This weight basis of course refers to the complete cable, copper core plus insulation. It is interesting to note that the total weight of insulation of all the cables is roughly equal to the total weight of metal, and from the point of view of weight reduction, both materials are thus equally important. The general substitution of al. for copper has not found favour in aircraft installations due to corrosion difficulties, especially for the smaller sections. Since however the larger sections (2.5mm² and upwards) account for 27% of the total metal weight, the utilisation of al. for the heavier sections is well worth considering. It is stated that the substitute of synthetic materials for the normal rubber insulation would lead to a reduction in weight of the total installation by about 10%.

R.T.P. Ref.	*Title and Journal*
	COCKPIT LAYOUT
27056 Gt. Britain	*Modern Cockpit Controls and Equipment.* (G. H. G. Garbett, Aeroplane, Vol. 60, No. 1563, 9th May, 1941, pp. 531-2.)
27808 Gt. Britain	*Fighter Cockpits (Past and Present Layout).* (Aeronautics, Vol. 4, No. 6, July, 1942, pp. 32-35.)
28781 Gt. Britain	*A Suggested Panel for Navigational Instruments.* (R. G. Page, Aeroplane, Vol. 61, No. 1583, 26th Sept., 1941, pp. 336-337.)
28882 Gt. Britain	*Instrument and Control Layouts.* (Flight, Vol. 40, No. 1712, 16th Oct., 1941, p. 256.)
191 Gt. Britain	*Uniformity of Cockpit Layouts.* (Flight, Vol. 41, No. 1723, 1st Jan., 1942, pp. 6-9.)
218 Gt. Britain	*A Plea for Less Cockpit Instruments.* (Flight, Vol. 41, No. 1724, 8th Jan., 1942, pp. 29-30.)

29107

AIRCRAFT ELECTRICITY AS THE AIR LINE OPERATOR SEES IT

(P. C. Sandretto, J.S.A.E., Vol. 48, No. 4, April, 1941, pp. 154-159)

The electric power consumption in the D.C.3 transport aircraft on a five hours' flight is analysed. Of the total consumption, about 73% is used for navigational purposes, 19.8 for service and 7.2 for operations. Details appear in the following tables.

TABLE I.

Operation Electricity, Douglas D.C.3 Plane

	Amp.	Amp.-Min.
Warning lights	1.2	360
Landing-gear warning lights	0.7	210
Engine starters	260	520
Fuel and oil pressure warning lights	1.1	66
Booster coils	3	6
Total..		1,162

TABLE II.

Navigation Electricity (for ditto)

	Amp.	Amp.-Min.
Windshield de-froster fan	1.0	300
Argon dynamotor and/or instrument spotlight ..	1.5	450
Pilot heater	14.0	4,200
Running lights	2.5	750
Compass, gyro and radio panel lights	1.0	300
Instrument panel lights	1.0	300
Radio-receiving dynamotor and receiver filament ..	7.3	2,190
Electrical instruments	1.0	300
Wing de-icer	1.5	450
Transmitting dynamotor	60	900
Transmitting filaments	15	450
Landing lights	70	1,050
Baggage pits	2	90
278-kc relay	0.4	2
Total		11,732

TABLE III.

Service Electricity (for ditto)

	Amp.	Amp.-Min.
Cabin side lights..	6.2	1,860
Buffet lights	1.0	300
Cabin warning lights	2.5	100
Seat belt warning	1.2	360
Companionway domelight	1.0	45
Stewardess call light	1.0	5
Cabin light relay..	0.5	30
Cabin dome lights	6.2	372
Entrance door light	1.7	105
TOTAL		3,177

The source of supply consists of 2 (12 v.) D.C. generators and 2 (65) amp. hr. storage batteries. The total weight is about 190 lbs., or 127 lbs. per kw. on a continuous rating of 1.5 kw. (the weight of cable and conduits is of the order of 300 lbs.).

On the D.C.4 (55,000 lbs. gross weight against 25,000 lbs. of the D.C.3) by stepping up to 24 volt and various other improvements (such as speeding up generators) it has been possible to obtain a continuous rating of 20 kw. for a weight of only 242 lbs., i.e., the specific weight has been reduced to about 20 lbs. per kw., whilst the conduit system weighs about 540 lbs.

The author is of the opinion that 24 v. D.C. will remain standard for some time, but that for much larger machines (gross weight 100,000 lbs.) A.C. current as 115 volts and frequencies ranging from 300–900 cycles will enable a further marked reduction in weight of the electrical power plant.

Cockpit Layout—*continued*

1145 Gt. Britain	*Short Stirling Cockpit (Photograph).* (Aeroplane, Vol. 62, No. 1605, 27th Feb., 1942, p. 338.)
1281 Gt. Britain	*Short Stirling Cockpit Layout (Photographs).* (Airc. Prod., Vol. 4, No. 41, March, 1942, p. 256.)
3621 U.S.A.	*Liberator* I *Cockpit Control (Photograph).* (Flight, Vol. 42, No. 1752, 23rd July, 1942, p. 92.)

CONTROLS

28686 U.S.A.	*Hydraulic Control System for Aircraft.* (H. L. Brown beck and P. M. Heldt, Autom. Ind., Vol. 85, No. 4, 15th Sept., 1941, pp. 20-25.)
194 Gt. Britain	*Saunders Tube Control (Push, Pull and Rotary).* (Flight, Vol. 41, No. 1723, 1st Jan., 1942, pp. 16-17.)
645 U.S.A.	*Aircraft Control Cables.* (R. F. Kolder, Aviation, Vol. 40, No. 11, Nov., 1941, pp. 78-79 and 170.)
962 Gt. Britain	*Simplified Cruising Control (Constant B.M.E.P. Operation).* (A. A. Barrie and J. B. Cutting, Flight, Vol. 41, No. 1730, 19th Feb., 1942, pp. 156-159.)
2249 U.S.A.	*Curtiss Wright Tell-tale Panel (Quick Check on* 47 *Details of Control.)* (Aero Digest, Vol. 40, No. 3, March, 1942, pp. 235-238, 311.)
2460 Gt. Britain	*Remote Controls for Aeroplanes.* (R. Hadekel, Airc. Eng., Vol. 14, No. 158, April, 1942, pp. 106-107.)
2904 Gt. Britain	*Standardised Controls.* (Airc. Prod., Vol. 4, No. 40, Feb., 1942, pp. 192-194.)
3089 Gt. Britain	*Boost Controls for Aero Engines.* (D. Ramsay, Airc. Eng., pp. 120-122, Vol. 14, No. 159, May, 1942.)

25074

SERVO OPERATION OF THE CONTROL SURFACES OF LARGE AIRCRAFT

(E. W. McDonough, Aero. Digest, Vol. 37, No. 2, Aug., 1940, pp. 76-80)

Prerequisites of a booster control system may be summarised as (1) use of conventional type control levers; (2) necessity for only a moderate control force by the pilot; (3) the presence of a certain amount of "feel" of the actual forces existing on the control surface; and (4) direct connection to control surfaces to provide a means for actuation in the event of hydraulic pressure failure.

Two available methods offer a solution to this problem; they may be classed as the "displacement feel," and the "load feel." In the former design, movement of the controls opens servo valves which immediately allow pressure to build up in the Sperry gyropilot cylinders. This causes the control surfaces to move to a position determined by the amount of movement in the controls.

The "displacement feel" system is disadvantageous in that it gives the pilot finger-tip control which may be dangerous in a quick emergency manœuvre. Furthermore, the pilot must learn to fly by displacement of the controls and the aeroplane's response to that displacement; the system not only lacks the customary "feel," but also control resistance is artificially built up by friction and springs.

On the other hand, the "load feel" system retains all the characteristics of mechanical control, the pilot "feeling" only a fraction of the resisting force as in the mechanical system. The mechanical characteristics of this system are aided by hydraulic power which can be designed to give any desired degree of assistance to the pilot.

1380

NEW DEVELOPMENTS IN SIMPLIFIED CONTROL

(R. H. Upson, Inst. Aeron. Sci., 10th Annual Meeting, Jan., 1942, pp. 1-12)

Problems of control are presented from a standpoint of simple operation rather than mere mechanical simplicity. Of first importance is the elimination of inconsistent or abnormal behaviour, in which spinning is classed. The influence of wing and engine position is discussed, and several advantages of car type of wheel arrangement brought out.

A primary control, in which flaps are co-ordinated with elevator, and rudder with ailerons, is advocated. In a possible supplementary pedal control, ground brakes are co-ordinated with air drag obtained by opposite deflection of two rudder surfaces.

Special problems, considered from a standpoint of simplified control, include stability against overturning on the ground, inertia loads on the wing, spiral stability, and control requirements for following a compass course.

The ideal aeroplane for private flying is described as being: outstanding in vision, incapable of spinning, comparable with a car in simplicity of control, yet with unquestioned superiority of cross-country performance.

893

ROLLER BEARINGS

(T. V. Buckwater, S.A.E. J., Vol. 50, No. 1, Jan., 1942, pp. 20-36)

This paper traces the introduction of tapered roller bearings into all phases of industry, manufacturing and transportation—particularly the automotive industry, the railroad industry, steel mills, oil industry, and machine tools.

Discussing design principles, the author brings out that one of the fundamental concepts of tapered roller bearing usage is that they must be mounted in pairs, and a second is that the bearings accommodate any combination of thrust and load; for high thrust reactions, the bearing is made with a steep taper. He points out that tapered roller bearings are rated in accordance with a speed factor, life factor, and application factor, explaining how each of these factors is derived.

In the remainder of the paper are discussed: Lubrication, extreme-pressure lubricant testing, types of tapered roller bearings, contact stresses in solid and hollow rollers, starting friction on railroad axles, crankshaft and crankpin application, machine-tool applications, steel rolling mill applications, and oil-well applications.

27608

DEVELOPMENTS IN GOODRICH DE-ICER

(Inter. Avia., No. 761, 24th April, 1941, p. 14)

The new patent No. 2237175 of the B.F. Goodrich Company of New York covers an improvement of the well-known Goodrich De-Icer system, which prevent the accretion of ice at the critical points of the aeroplane mechanically by means of pulsating rubber "overshoes." The overshoe is faired to the wing by means of a metal strip on which the ice formed could not be removed. The improvement on the method so far in use consists of a secondary layer of soft rubber which is attached on the main de-icer and is stretched tauht over the common attachment strip. Every pulsation of the "primary" de-icer is communicated to the "secondary" overshoe and prevents the formation of ice also in the hitherto unprotected region.

R.T.P. Ref.	*Title and Journal*
	HEATING
29052 U.S.A.	*Design of Heating and Ventilating Systems in Transport Aircraft.* (A. E. Smith, Aero Digest, Vol. 38, No. 5, May, 1941, pp. 139, 246-249.)
	WINDSCREENS, WINDOWS AND HOODS
26376 Gt. Britain	*Transparent Coverings (for Cockpits, Turrets, etc.), Machining and Installation of Units made from Plastic Sheet.* (Airc. Prod., Vol. 3, No. 29, March, 1941, pp. 77-8.)
27742 U.S.A.	*Plexiglass for Aircraft.* (Aviation, Vol. 40, No. 5, May, 1941, pp. 42-43.)
28119 U.S.A.	*Plexiglass Nose Section of B.26.* (American Chem. Soc. (News Edition), Vol. 19, No. 12, 25th June, 1941, pp. 700-701.)

R.T.P. Ref.	Title and Journal
	Windscreens, Windows and Hoods—*continued*
863 U.S.A.	*Application of Plexiglass to Bomber Construction.* (Aero. Digest, Vol. 39, No. 6, Dec., 1941, pp. 239-40.)
872 U.S.A.	*Transparent Plastic for Bomber Nose Section.* (Aero. Digest, Vol. 39, No. 6, Dec., 1941, p. 259.)
884 Gt. Britain	*Shatter-proof Plastics for Pressure Cockpits.* (British Plastics, Vol. 13, No. 152, Jan., 1941, p. 259.)
2916 Gt. Britain	*Cabin Windows (Patent No.* 534761). (Airc. Prod., Vol. 4, No. 40, Feb., 1942, p. 218.)
3020 U.S.A.	*Roxalin Safety Glass.* (Aviation, Vol. 41, No. 3, March, 1942, p. 97.)
3165 Gt. Britain	*Reflection Proof Glass.* (Airc. Prod., Vol. 4, No. 43, May, 1942, p. 331.)
3886 Germany	*Double Window with Dry Air Pocket for Pressure Cabins. (Patent No.* 721874). D. V. L., Flugsport, Vol. 34, No. 15. (Patent Coll. No. 33), 22nd July, 1942, p. 233.)

25587

NEW TYPE OF SAFETY GLASS

(British Plastics, Vol. 12, No. 137, Oct., 1940, p. 163)

The I.G. Farbenindustrie of Germany has developed a new type of safety glass which leaves no splinters and provides remarkable adherence between laminations. Two thin sheets of glass are held together by an interlay of plastic material. This plastic is produced by polymerising sixteen molecules of vinyl acetate and one molecule of dimethyl maleate, which is then saponified by acetylation with butylaldehyde. To 100 parts of the resultant substance are added 66 parts of isoheptylic ether salt of diglycolic acid, and the whole is plasticised with 11 parts of methoxy-butanol. This is then heated to 80° C. and thoroughly mixed together. It can then be rolled into a sheet which is pressed between two thin sheets of ordinary glass and heated to 120° C. The whole is finally cooled under pressure. Adherence between the glass and the plastic is said to be very remarkable.

25916

FIBERGLAS, NEW BASIC RAW MATERIAL

(G. Slayter, Ind and Eng. Chem. (Industrial Ed.), Vol. 32, No. 12, 2nd Dec., 1940, pp. 1568-71)

Glass fibres possess desirable properties not found in any other commercially available material. They are produced either as a wool-like fibre, largely used for thermal insulation, or as a textile fibre, employed to form yarns, threads and woven fabrics. Glass fibres are incombustible, non-absorptive, chemically stable and resistant, unattacked by fungus or vermin and they possess extraordinary tensile strength, electrical properties and heat resistance. Their production, properties and uses are described.

The wool forms are used for insulation of houses, ships, trains, aircraft, etc., and for industrial insulation at temperatures from below 0° to over 1,000° F. Textile forms are used for electrical insulation, electrical storage battery retainer mats, chemical and fume filtration, etc.

R.T.P. Ref.	Title and Journal
	INTERIOR FITMENTS
2275 U.S.A.	*Sound Insulating Glass Fibre Wool.* (Aero. Digest, Vol. 40, No. 1, Jan., 1942, pp. 259-260.)

30053

DINGHIES FOR BRITISH FIGHTER PILOTS

(Inter. Avia., No. 782, 24th Sept., 1941, p. 20)

When folded the dinghy forms a cushion measuring 15 inches square by 3 inches in thickness which is strapped to the seat-type parachute next to the figure. The dinghy is inflated by means of a carbon-dioxide cylinder attached to it and can carry a weight of 400 lbs. It is approximately rectangular in shape and takes into account the weight distribution of a seated person by means of the varying diameter of the carrying tube. Its equipment includes a sea-drogue to prevent drift, a bailer, stoppers for possible perforations of the dinghy, an auxiliary air pump, two paddles, and a small supply of water-tight packed chocolate. To the bottom of the dinghy is attached a canvas water bucket which, when filled with water, keeps the head of the dinghy down as the pilot climbs in. The new dinghies are of bright yellow colour and provided with complete instructions for use in English, French, Polish and Czech.

2900

METHOD OF STOWING RUBBER DINGHY ON AIRCRAFT

(Flugsport, Vol. 34, No. 11, 27th May, 1942, pp. 170-171)

Two photographs illustrate the boat housed, in a folded condition, in the top of the fuselage of a twin-engined aircraft behind the cockpit. The compartment (apparently four feet long, two feet wide, and three feet deep) is fitted on top with a quick-release cover plate conforming to the shape of the fuselage. Release of the cover by the wireless operator opens simultaneously the CO_2 bottle for filling the boat. The latter is packed in such a way that the process of inflation causes the boat to be automatically ejected within a few seconds of pulling the release.

R.T.P.
Ref.

FIRE EXTINGUISHER SYSTEMS

1289 U.S.A. — *Extinguishing Fires in the Air (Photographs).* (Flying and Pop. Av., Vol. 30, No. 2, Feb., 1942, p. 58.)

1867

PROTECTION AGAINST POWER PLANT FIRES IN THE AIR (DIGEST)

(G. L. Pigman, S.A.E.J., Vol. 50, No. 2, Feb., 1942, pp. 55-56)

General objectives of C.A.A. fire-test programme :—

(1) To determine the characteristics necessary for adequate power plant fire detectors ; to develop such detectors if none are available ; and to determine their proper location in typical power plant installations.

(2) To determine the possibilities of extinguishing fires in aircraft power plants ; to evaluate various fire-extinguishing agents for this application ; and to determine the best methods of application of these agents.

(3) To determine the temperatures encountered in the cowling, firewall nacelle, and in the wing during typical oil and gasoline fires, and to investigate the fire-resisting qualities of various materials used for these parts.

(4) To determine the causes of ignition of petrol and oil fires and means whereby these dangers might be reduced.

Some of the extinguishing agents tried by means of various arrangements of different types of nozzles were carbon dioxide, methyl bromide, carbon tetrachloride, and commercial products containing sodium bicarbonate and potassium carbonate. Of these, the choice narrowed down to carbon dioxide and methyl bromide, with methyl bromide being rated as most efficient.

Detectors tested were of five general types : metal expansion types, fusible alloy types, thermocouple types, and ionisation types. Concluding his discussion of detectors, the author states that there are available satisfactory unit-type detectors, and that there is strong promise of satisfactory continuous-type detectors within the near future.

The following are among the general conclusions presented with reference to the materials phase of the problem :—

(1) The integrity of conventional aluminium-alloy monocoque nacelle structure can

be seriously jeopardised by engine fires within a few seconds from the start of such fires.

(2) The aluminium-alloy N.A.C.A. cowling is not damaged by severe engine fires of long duration.

(3) Portions of the accessory cowling and nacelle skin reach temperatures of 2,000° F. during a fire, which cause aluminium alloys to melt and will remove practically all load-bearing ability from stainless steel.

R.T.P. Ref.	*Title and Journal*
	COVERING, PANELLING AND PROTECTIVE METHODS
25923 U.S.A.	*Rubber Coatings on Metals.* (H. E. Cook, Metal Progress, Vol. 38, No. 4, Oct., 1940, pp. 430-1.)
25924 U.S.A.	*Plating of Aircraft Parts.* (G. E. Stoll, Metal Progress, Vol. 38, No. 4, Oct., 1940, p. 435.)
26070 U.S.A.	*Lockheed's New Photo-Loft-Template Process.* (Aviation, Vol. 39, No. 12, Dec., 1940, p. 111.)
26378 U.S.A.	*Photographic Lofting : Lockheed Aircraft Corporation's Method for Making Templates and Tooling Layouts.* (Airc. Prod., Vol. 3, No. 29, March, 1941, pp. 85-6.)
26716 U.S.A.	*Photo Lofting in the U.S.A.* (Inter. Avia., No. 747, 30th Jan., 1941, pp. 9-10.)
28803 U.S.A.	*The Camera in the Planning Loft.* (M. Lorant, Aeroplane, Vol. 61, No. 1584, 3rd Oct., 1941, pp. 374-75.)
29259 U.S.A.	*Sheet Metal Drafting, Part I (Surface Geometry).* (C. Belsky, Aero. Digest, Vol. 39, No. 2, Aug., 1941, pp. 152-160 and 223.)
29262 U.S.A.	*New "Roxalin" Fabric Finish for Aircraft Speed Production.* (W. F. Smith and A. B. Marsh, Aero. Digest, Vol. 39, No. 2, Aug., 1941, pp. 175-176, 224-227.)
29277 U.S.A.	*Superfinish—Its Aircraft Application.* (M. W. Petrie, Aero. Digest, Vol. 38, No. 4, April, 1941, pp. 125-130.)
29712 Gt. Britain	*Rapid Construction of Sheet Templates (Westland Aircraft).* (Engineering, Vol. 152, No. 3958, 21st Nov., 1941, pp. 407-408.)
205 Gt. Britain	*Template Manufacture (Westland Aircraft).* (Airc. Prod., Vol. 4, No. 39, Jan., 1942, pp. 164-165.)
1208 Gt. Britain	*Metal Spraying.* (Pitcairn Met. Ind., 23rd Jan., 1942, pp. 50-51.) (Abstract in Met.-Vick Tech. News Bull., No. 802, 20th Feb., 1942, p. 9.)
1516 Gt. Britain	*Metal Coating.* (Wein, Met. Finishing, Dec., 1941, pp. 666-672.) (Met. Vick. Tech. News Bull., No. 800, 6th Feb., 1942, p. 13.)
2256 U.S.A.	*Methods of Template Reproductions.* (C. O. Prest, Aero. Digest, Vol. 40, No. 3, March, 1942, p. 240.)
2268 U.S.A.	*Production Metallising.* (H. E. Linsey, Aero. Digest, Vol. 40, No. 1, Jan., 1942, pp. 154-159, 248-249.)
2791 U.S.A.	*Rust Protection.* (Chem. and Ind. (News Ed.), Vol. 20, No. 8, 25th April, 1942, p. 560.)
2813 Gt. Britain	*Synthetic Resins for Surface and Protective Coatings.* (E. A. Bevan, Chem. and Ind., Vol. 61, No. 24, 13th June, 1942, pp. 261-267.)
3452 Gt. Britain	*Electro-deposition of Metals.* (S. Murray, J. Inst. Prod. Engs., Vol. 21 No. 5, May, 1942, pp. 192-203.)

1934
SURFACE PROTECTION OF AIRCRAFT BY MEANS OF PAINTS AND LACQUERS

(W. JAEGER, Der Flieger, Vol. 21, No. 1, January, 1942, p. 20)

It is now generally recognised that a smooth external surface (especially of the wings) is of the greatest importance for high-speed aircraft. Surface protection by anodic oxidation although attractive from the point of view of weight, suffers from the drawback of producing a relatively rough surface, even if, as usual, a subsequent coating of lacquer is applied. Modern acryl resin lacquers weigh about 80 gm. per m.^{2} for the usual single coat. As two or even three coats may be necessary in order to obtain sufficient smoothness of the outer skin of anodised material, the author suggests that anodic treatment should be reserved for those structural parts of the aircraft for which surface friction is not critical.

When comparing different methods of surface protection, increase in frictional drag may be of much greater importance than weight added.

29102
THE PROTECTION OF DURALUMIN IN AIRCRAFT STRUCTURES

(A. IACOBONI, Atti di Guidonia, Nos. 45-47, 20th March, 1941)

In a preliminary discussion it is shown that, in order to assess the real protective efficiency of a given coating and to obtain a guide in making a suitable selection, in addition to corrosion tests under conditions which (with the surrounding corrosive medium and the state of the material) approach the actual working conditions as closely as possible, further investigations and tests are necessary in order to ascertain the numerous other characteristics of the protective layer. A complete series of laboratory experiments has been carried out and from the results it has been possible to establish the particular system which is the most suitable under particular operative conditions for the protection of duralumin in aircraft constructions. At the same time, with the different processes of protection under investigation, the causes of their particular behaviour are revealed and the different manner and form in which the phenomenon of corrosion takes place and develops under the different conditions of corrosion and with different protective systems are indicated.

26716
PHOTO LOFTING IN THE U.S.A.

(Inter. Avia., No. 747, 30th Jan., 1941, pp. 9-10)

For the manufacture and assembly of individual construction elements of mainly irregular curvatures, such as ribs, transverse frames and bulkheads, which in the finished aircraft determine the curved surfaces, the aircraft industry has for a long time employed a method it borrowed from the shipbuilding industry. For these parts full-size drawings were made and traced on metal sheets by hand which afterwards were cut out and used as templates. In order to simplify this complicated and lengthy operation which caused a great loss of time between the design and the quantity production of the aeroplane, an engineer of the Lockheed Aircraft Corporation has developed a method which has already been adopted by several aircraft firms. The engineering drawings are photographed on 14 inch by 17 inch plates, and subsequently projected to the full size of the aircraft parts on sensitised template metal sheets by means of a projector camera. Immediately afterwards the drawing is again projected in full size on a sensitised tracing cloth which is used for the preparation of the blueprints; in the meantime the template is cut out and can immediately be employed in the shop. In addition to a great saving of time, the photo-loft process has the advantage of eliminating a whole series of possible sources of error.

28497
REPRODUCTION OF WORK TEMPLATES BY THE ELECTROLYTIC PRESS

(Aviation, Vol. 40, No. 4, April, 1941, p. 113)

Said to be faster and more economical than the photo-loft-template process, the new method is simple and the materials used are standard in most plants. A master layout is scribed from an engineer's drawing on a galvanised iron sheet about .040 inch thick, one face of which has been prepared by a special coating of insulating paint. Layout thus formed is sprayed with a transfer solution and the wetted surface is pressed

into firm and uniform contact with a copy plate in a specially built press. An electric current passing between the two plates results in the layout of the master plate being transferred instantly to the copy plate. Given a thin protective coating, the copy plate is then ready for immediate use by the template cutters. Total time required from the moment the copy plate is placed in the press with the master plate until it is washed, dried, and ready for the template department is not more than five minutes.

29266

PHOTO-LOFT TEMPLATE PROCESS FILM DEVELOPED

(Aero. Digest, Vol. 39, No. 2, August, 1941, pp. 196-198)

With the use of Matt. Transfer Film, produced by Eastman Kodak, engineering drawings can be printed either by contact or by projection on photo-sensitive metal sheets and the processed plates bearing the photographic image are then sent directly to the Template Department to be cut out and used as a pattern. The templates are made by cutting around the photographic outline by a saw or mechanical shears. Other machining operations to which the photo-sensitised metal sheets are subjected are filing, drilling and punching. By this means the costly and time-consuming step of making the layouts on metal by hand from the blueprints or the necessity of duplicate inspection, is avoided. Also, by this method copies of a drawing can be produced for checking purposes, for blueprints, by using photographic tracing cloth, or for use in redesigning a part.

In the contact method of making prints on photo-sensitised metal, the engineering drawings are made on metal plates which have been given a coating of a material which will fluoresce in the presence of X-rays. This coating is likewise of such a nature that it can be drawn upon satisfactorily. If positive prints on the metal are desired, a photo-sensitive glass plate is placed in contact with a treated surface of the plate bearing the mechanical drawing and the exposure is made by X-ray through the back of the metal plate. The processed glass negative is then printed on to a sheet of photo-sensitised metal in the usual way. If a mirror image negative on metal is used for the templates, the photo-sensitised metal sheet is placed in contact with the above-treated metal drawing sheet and exposed through the back of the metal by X-ray. The negative mirror images obtained may be made into " right " images by simply turning over the finished template.

The Lockheed Aircraft Corp., a pioneer user of Eastman Kodak Matte Transfer Film, has made satisfactory use of enlargements of mechanical drawings on photo-sensitised metal plates. In this process the mechanical drawings are made directly upon lacquered metal sheets. The drawings are then photographed on glass plates in a special camera. The glass negatives are then enlarged on to the photosensitised metal sheets. By this method photo-templates as large as 4 feet by 12 feet have been made.

It has been found that the most simple and effective method of producing sheets of photo-sensitised metal consists of laminating Matte Transfer Film to lacquered metal sheets. The film consists of a sensitive emulsion coated on a thin film support, the latter backed by a paper base. When used, the sensitised strip is transferred (or stripped) from the supporting paper base to the lacquered metal plate. This film has a matte surface, so that it will take a pencil line in case changes or additional developments on the processed photographic image are desired.

At present, width of Matte Transfer Film is limited to a maximum of 34.5 inches. If wider plates are desired, several strips of film are used to give the desired width and the plate is passed through the machine the required number of times for proper lamination of the film.

27067

PROTECTIVE FINISHES FOR ALUMINIUM AIRCRAFT SURFACES

(Cordy Steel, 10th March, 1941, pp. 66, 72 and 102)

Corrosion may easily reduce the endurance limit of aluminium or aluminium alloy by as much as 67%, and hence the retention of maximum physical properties which is so necessary in aircraft construction, necessitates adequate attention to corrosion prevention. In this article the author details the factors involved and various means of corrosion prevention and describes the practice employed by the Curtiss-Wright Corp. of U.S.A., which involves the production of a tough protective film. (Illustrated by three photographs.)

26696
TECHNICAL DEVELOPMENTS IN METAL FINISHING DURING 1940

(HALL, Hogaboom, Metal Finishing, Jan., 1941, pp. 2-7, 10)

Summaries of papers on metal finishing published during the year 1940 are presented in a form designed for ease of reference. The abstracts are classified in sections according to the purpose and type of the finish and contain details of many U.S. patents on electro-plating.

(*Abstract supplied by Research Dept., Met.-Vick.*)

76
RECENT EXPERIMENTS IN CONNECTION WITH THE SPRAYING OF STEEL

(R. R. SILLIFANT, Engineering, Vol. 144, pp. 526-528)

The spraying of various carbon and alloy steels for the purpose of resurfacing and building up worn parts has been adopted as standard practice in many engineering works. The purpose of the author is to explain some experiments carried out by him with a view to improving the quality of the deposit, using a wire-fed pistol. These pistols are designed normally to use compressed coal gas, hydrogen or acetylene as the fuel gas, air being the impelling medium for the atomised particles. Under these conditions each sprayed particle is enveloped by a skin of oxide which reduces the quality of the deposit and reduces its tensile strength. The author concluded that oxidation can occur in four distinct phases: (1) in the flame zone, excess O_2 being present; (2) in the air blast on removal from wire; (3) on the surface of the sprayed article, by exposure to air blast; (4) on the surface of the article if the latter becomes excessively heated. Phases (1) and (4) should be considerably reduced by having a neutral flame and keeping the work cool; phases (2) and (3) are avoidable if nitrogen instead of air is used as the impelling medium. It appears that approximately neutral flames of sufficient stability can only be obtained with acetylene. Using this type of flame in conjunction with N_2, the author in fact obtained deposits of improved quality, especially after two hours connecting at 900 C. The optimum temperature will depend on the nature of the sprayed material, and to obtain the best results, the surface of the article has to be subjected to a preliminary roughening (screw threading at a very fine pitch).

288
METAL SPRAYING PROCESSES AND SOME CHARACTERISTICS OF THE DEPOSITS

(C. E. ROLLASON, Journal of the Institute of Metals, Vol. 60, No. 1, 1937, pp. 35-54)

Spraying pistols using wire, powder, and molten metal are described, together with comparative details. The nature of the sprayed deposit is discussed. A few corrosion tests using intermittent salt-spray have been made on zinc and aluminium deposits and on painted zinc coats.

Using the three types of pistol, comparative tests of aluminised surfaces have been made and heat-treated nickel-chromium-iron coatings were found to have good resistance to oxidation at elevated temperatures. Data also given for porosity, oxide content of sprayed copper, and hardness of sprayed metals.

The hardness of sprayed deposits is becoming more important, owing to the increased use of the process in the building up of worn articles. It is greatly affected by the amount of oxide and porosity of the coat, because a material full of pores has less resistance to penetration than sound metal, consequently yielding a lower Brinell number. On the other hand, oxide particles in the same material tend to give a high scratch hardness. In mild steel the oxide present as sprayed makes the material almost unmachinable, but annealing decreases the hardness due to agglomeration of oxide. It was found, when using a wire pistol, that the hardness was increased by increasing the speed of wire feed, by higher oxygen pressure and also, to a less degree, by higher hydrogen pressure, optimum values being given.

There are many different opinions in the literature on the subject regarding the oxide content of the sprayed deposit. To obtain deposits low in oxide it would appear advisable to use a slightly reducing flame and to reduce the nozzle distance so far as

it is possible without overheating the base. Unfortunately, a pistol using a reducing flame is not working at its maximum efficiency. The practice of preheating the article advocated some ten years ago is now seen to be undesirable.

In one German pistol carbon dioxide is used for atomising in the case of low melting point metals, and the use of nitrogen instead of air has also been suggested, but not worked commercially.

287

METAL SPRAYING—FUNDAMENTALS AND APPLICATIONS

(R. L. DENNISON, J. Am. Soc. Nav. Engs., Vol. 50, No. 1, Feb., 1938, pp. 85-106)

Though oxidation may be lessened by using a reducing flame and holding the pistol close to the work, this has been found impracticable. The spraying of 0.9% carbon steel on a bar of 0.30% carbon steel and substituting nitrogen for air as the impelling medium has shown improvement in the structure of the sprayed coating and signifies reduction in oxidation.

Another theory is that little or no oxidation takes place during spraying but that each particle is oxidised after deposition. Investigations on the oxidation of sprayed copper coatings show that the substitution of nitrogen for air does not give appreciable effect in reducing the amount of oxides formed. The powder system of spraying is stated to give more oxidation than the wire system, however, as there is no general agreement on the improvement through using nitrogen instead of air, and the cost of using the former would offset any gain, it is now believed that preheating the surface tends t o encourage the formation of an oxide film, and is therefore generally practised.

28927

METAL SPRAYING WITH AN ELECTRIC ARC-GUN

(J. Am. Soc. Nav. Engs., Vol. 53, No. 3, Aug., 1941, pp. 688-9)

A new method of metal spraying has been developed by Dr. M. U. Schoop of Switzerland, originator of the metal-spraying process, which makes use of a spray gun utilising an electric arc to melt the metal to be deposited. Hitherto, the metal-spraying process has depended upon a gas flame of some kind to melt the metal before being deposited on the base surface.

The new Schoop process consists essentially of short-circuiting two conducting wires which pass through the spray gun, atomising each drop of metal melted by the resulting arc, and projecting the atomised metal by means of a compressed air blast on the surface to be metallised. A small luminous arc is formed at the breaking point, insuring the continued melting of the wires, which are constantly being fed forward by means of a turbine. Although the compressed air blast directed through the arc may be fed into the gun at pressures ranging from 60 to 120 lbs. per sq. inch, the arc is reported to be entirely stable.

The new process of metal spraying is claimed to be highly economical and efficient. It is said that about twenty-two lbs. of carbon steel or stainless steel wire can be sprayed during each hour of operation. In many cases, the pre-treatment of the surfaces by sand-blasting heretofore required, can be dispensed with because of the increased strength of bond secured by this method of deposition. Thus, if a glass plate is electro-metallised with aluminium or steel by this process, and an attempt is made to remove the deposited metal, a layer or " skin " of glass will also be torn off. It appears that owing to the electric arc, the temperature of the sprayed metal particles is so high that they melt into the surface against which they are propelled, rather than becoming merely a surface layer.

28938

A NEW CHROMISING PROCESS

(RUDORFF, Met. Ind., 26th Sept., 1941, pp. 194-5)

Although there are several ways in which the high corrosion resistance of chromium can be utilised for the protection of iron and steel, the most widely known chromium plating requires an intercoating between the steel surface and the chromium layer. The author states that much greater wear resistance and service life can be obtained by resorting to chromium impregnation, the process of which is described, in which an integral surface layer is formed by a diffusion process employing an atmosphere containing chromous chloride.

(Abstract supplied by Research Dept., Met.-Vick.)

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P.G.412	The Park Gate Iron and Steel Co., Ltd., Park Gate Works, Rotherham.
Pheonoglaze	Phonoglasyl, Ltd., 466, London Road, Croydon.
Plasoleum	Revertex Sales Co., Ltd., King William Street House, Arthur Street, London, E.C.4.
Plastol	Aero Research, Ltd., Duxford, Cambs.
Pop Rivets	George Tucker Eyelet Co., Ltd., Birmingham.
Protal	Messrs. Airco, Ltd., Eagle House, 109, Jermyn Street, S.W.1.
Prozol	John Hall & Sons, 1-5, St. Pancras Way, N.W.1.
Prana	Sparklets, Ltd., London, N.18.
Purolator	Automotive Products Co., Ltd., Leamington Spa.
P.V.X.	Technical Rubber Co., Ltd., 58, Pentonville Road, London, N.1.

Q

Quickwork	Oliver Machinery Co., Ltd., 196, Deansgate, Manchester.

R

RELT	The Empire Rubber Co., Dunstable, Beds. Bury Felt Manufacturing Co., Ltd., Hudcar Mills, Bury, Lancs.
RESISTA	Hertfordshire Rubber Co., Ltd., Letchworth, Herts.
RHODOID	May & Baker, Ltd., 42, St. Paul's Churchyard, E.C.4.
ROVAL	International Corrodeless, Ltd., Lockfield Avenue, Enfield.
ROSS AIRVALVES	The Wellman Smith Owen Engineering Corp., Ltd., Victoria Station House, Victoria Street, London, S.W.1.
RUBBAGLEX	Impervia, Ltd., 3, Grosvenor Gardens, London, S.W.1.
RUBAZOTE	Expanded Rubber Co., Ltd., Mitcham Road, Croydon.

S

SAUNDERS FLYING CONTROL	Brown Bros. (Aircraft), Ltd., Great Eastern Street, London, E.C.2.
SEALAC	Magnal Products, Ltd., Warmley, Bristol.
SEALUBE	Parker Appliance Co., Los Angeles, U.S.A.
SHAKEPROOF	Barber & Colman, Ltd., Marsland Road, Brooklands, Manchester.
SIGMA	E. H. Jones (Machine Tools), Ltd., Edgware Road, The Hyde, London, N.W.9.
SIERAY	Siemens Electric Lamps and Supplies, Ltd., 30/39, Upper Thames Street, London, E.C.4.
SIF-BRONZE	Suffolk Iron Foundry (1920), Ltd., Siff Bronzo Works, Stowmarket.
SIL-FOS	Johnson, Matthey & Co., Ltd., 73-82, Hatton Garden, London, E.C.1.
SINOC	'O' Cedar, Ltd., Slough, Bucks.
SIMPLIMIL	Alfred Herbert, Ltd., Coventry.
SKF	The Skefko Ball-bearing Co., Ltd., Luton.
SKYHI	Harry Miller & Co., London, N.W.10.
SKYFLEX	Harry Miller & Co., London, N.W.10.
SKILSAW	British Equipment Co., Ltd., 74, Ixworth House, Ixworth Place, London, S.W.3.
SLYDLOCK	Edward Wilcox & Co., Ltd., Sharston Road, Wythenshawe, Manchester.
SOS RUBBER	T. B. Andre Co., Ltd., Kingston Bypass, Surbiton.
SOZAL	Sozal, Ltd., Dashwood House, Old Broad Street, London, E.C.2.
SPEEDFIX	Ofrex, Ltd., 15, Newman Street, Oxford Street, W.1.
SPEEDAX	B. Elliott & Co., Ltd., Victoria Works, Victoria Road, Willesden, N.W.10.
SPEETOG	Speed Tools, Ltd., 10-16, Rathbone Street, Oxford Street, London, W.1.
STADEX	Starch Products, Ltd., Gludex Works, Mill Street, Slough, Bucks.
STENOFELT	L. Rumbold & Co., Ltd., King's Gate Place, Kilburn, N.W.6.
STATFILE	Photostat, Ltd., Dept. 3, Adelaide House, King William Street, London, E.C.4.
STAYBRITE	Firth Vickers Stainless Steels, Ltd., Sheffield.
STERMET	Sterling Meters, Ltd., Coventry.
STERNOCLEANSE	Sternol, Ltd., Finsbury Square, London, E.C.2.
STORMOR	J. Glover & Sons, Ltd., 47, Groton Road, London, S.W.18.
STROBOTAC	Claude Lyons, Ltd., 180-182, Tottenham Court Road, London, W.1.
SUPREME	L. H. Hawkins & Co., Ltd., 30-35, Drury Lane, London, W.C.2.
SUPERGYPE SUPERPYRO	Autogenous Cases, Ltd., 787, Ibex House, Minories, E.C.3.
SYNTHA	Ronald Trist & Co., Ltd., Bath Road, Slough, Bucks.

T

TANCO	J. Burns, Ltd., Wangye Works, Chadwell Heath, Essex.
TEXOLEX	The Bushing Co., Ltd., Hebburn-on-Tyne.
THERMOMETAL	Henry Wiggin & Co., Ltd., Grosvenor House, Park Lane, London, W.1.
THERMINDAX	J. M. Steel & Co., Ltd., Kern House, 36, Kingsway, W.C.2.
TINTOLITE	Canning & Co., Ltd., Gt. Hampton Street, Birmingham.
TITEGRIP	F. Gilman (B.S.T.), Ltd., Carlton House, 195, High Street, Smethwick 41, Staffs.
TOGGLE PLIERS	Funditor, Ltd., 3, Woodbridge Street, London, E.C.1.
TRAFFOLYTE	Metropolitan-Vickers, Ltd., Trafford Park, Manchester.
TRU-LAY	British Line Products, Ltd., Worcester Road, Stourport-on-Severn.
TRU-LOCK	
TYNOLEX	The Bushing Co., Hebburn, Co. Durham.

V

VELLUTEX	Chillcotts, Ltd., 25, Short Street, Blackfriars, S.E.1.
VISKRINGS	The Viscose Development Co., Ltd., Woldham Road, Bromley, Kent.

W

WEBSTER	Broadway Engineering Co., Ltd., Carlisle Road, Hendon, N.W.9.
W.G.I.	Weymouth Gauges and Instruments, Ltd., Brunel Road, East Acton, W.3.
WIMET	A. C. Wickman, Ltd., Coventry.

Z

ZENITH	B. Elliott & Co., Ltd., Victoria Works, Victoria Road, Willesden, N.W.10.
ZONAZ	W. Canning & Co., Ltd., 133-137, Gt. Hampton Street, Birmingham.

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1. Abrasives
The Anglo Abrasive Works, Ltd.
S. T. Coburn & Son, Ltd.
Richard Lloyd & Co., Ltd.
Norton Grinding Wheel Co., Ltd.
Turner Machine Tools, Ltd.

2. Accumulators
Henry Berry & Co., Ltd.
Crompton Parkinson, Ltd.,
Exide & Drydex Batteries
Rotax Ltd.

3. Acetylene Welding and Cutting
Commercial Structures, Ltd.
George H. Elt, Ltd.
Hoggett, Young & Co., Ltd.
Laystall Engineering Co., Ltd.
The M.G. Car Co., Ltd.
Suffolk Iron Foundry (1920), Ltd.
Thorn & Hoddle, Ltd.
Tipsy Aircraft Co., Ltd.
A. Warden & Co., Ltd.

3a. Adhesive Tapes
Industrial Tapes, Ltd.

4. Aero-engines
Alvis, Ltd.
The Bristol Aeroplane Co., Ltd.
A.B.C. Motors, Ltd.
The De Havilland Aircraft Co., Ltd.
Rolls-Royce, Ltd.
The Standard Motor Co., Ltd.

5. A.G.S.
Aircraft Materials, Ltd.
D. H. Bonnella & Son, Ltd.
Morrisons Engineering, Ltd.
M. & B. Plastics, Ltd.
Rolls Razor, Ltd.

6. Ailerons
Morrisons Engineering, Ltd.
Tipsy Aircraft Co., Ltd.

7. Air Compressors
A.B.C. Motors, Ltd.
Aeraspray Manufacturing Co., Ltd.
Aerostyle, Ltd.
William Allday & Co., Ltd.
Broom & Wade, Ltd.
John Cashmore, Ltd.
The Coventry Victor Motor Co., Ltd.
E.M.B. Co., Ltd.
Joseph Evans & Sons (Wolverhampton), Ltd.
Pneumatic Components, Ltd.
Reavell & Co., Ltd.
Spencer & Halstead, Ltd.
Tangyes, Ltd.
Tilghman's Patent Sand Blast Co., Ltd.
Volspray, Ltd.
A. H. Wilkes, & Co., Ltd.
Whittaker, Hall & Co. (1929), Ltd.

8. Air Conditioning.
Airscrew Co., Ltd.
British Trane Co., Ltd.
Controlled Heat & Air, Ltd.
Guyson Industrial Equipment, Ltd.
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9. Aircraft
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Folland Aircraft, Ltd.
Morrisons Engineering, Ltd.
Phillips & Powis Aircraft, Ltd.
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The Standard Motor Co., Ltd.
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10. Air Cylinders
Aeraspray Manufacturing Co.,Ltd.
Broadway Engineering Co., Ltd.
Broom & Wade, Ltd.

11. Airline Equipment
E. P. Barrus, Ltd.
George H. Elt, Ltd.
Morrisons Engineering, Ltd.
The G.Q. Parachute Co., Ltd.
Pneumatic Components, Ltd.
A. Schrader's Son
The British Thermostat Co., Ltd.
The Visco Engineering Co., Ltd.

12. Airscrews
Airscrew Co., Ltd.
The De Havilland Aircraft Co., Ltd.
Northern Aluminium Co., Ltd.

13. Alloys, non-ferrous
Aircraft Materials, Ltd.
The British Aluminium Co., Ltd.
The Delta Metal Co., Ltd.
High Duty Alloys, Ltd.
I.C.I. Metals, Ltd.

13a. Aluminising
Metallisation, Ltd.

14. Aluminium and Alloys
Birmetals, Ltd.
Birmingham Aluminium Casting (1903) Co., Ltd.
The British Aluminium Co., Ltd.
John Dale, Ltd.
High Duty Alloys, Ltd.
Light Metal Forgings, Ltd.
I.C.I. Metals, Ltd.
Northern Aluminium Co., Ltd.

15. Aluminium (Bar)
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The British Aluminium Co., Ltd.
John Dale, Ltd.
High Duty Alloys, Ltd.
I.C.I. Metals, Ltd.
Northern Aluminium Co., Ltd.

16. Aluminium (Sheet)
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The British Aluminium Co., Ltd.
High Duty Alloys, Ltd.
I.C.I. Metals, Ltd.
Northern Aluminium Co., Ltd.

17. Aluminium (Tubing)
Birmetals, Ltd.
The British Aluminium Co., Ltd.
High Duty Alloys, Ltd.
I.C.I. Metals, Ltd.
Northern Aluminium Co., Ltd.
Serck Radiators, Ltd.

18. Aluminium (Wire)
Birmetals, Ltd.
The British Aluminium Co., Ltd.
High Duty Alloys, Ltd.
I.C.I. Metals, Ltd.
Northern Aluminium Co., Ltd.

19. Anodising
Airwork General Trading Co., Ltd.
Brailey Electroplaters, Ltd.
W. Canning & Co., Ltd.
Morrisons Engineering, Ltd.
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20. Anti-vibration Units
British Tyre & Rubber Co., Ltd.
Metalastik, Ltd.
The North British Rubber Co., Ltd.
Silentbloc, Ltd.
The Sperry Gyroscope Co., Ltd.
Wilkinson Rubber Linatex, Ltd.

21. Asbestos
Coopers Mechanical Joints, Ltd.
J. A. Harrison & Co. (Manchester) Ltd.
Turner Brothers Asbestos Co., Ltd.
Veneercraft, Ltd.

22. Assembly Equipment
L. J. H. Ballinger
R. K. Dundas, Ltd.
George H. Elt, Ltd.
Esavian, Ltd.
Gratton Tools, Ltd.
Geo. W. King, Ltd.
S. Grahame Ross, Ltd
Monarch Tool Co., Ltd.
Ratcliffe Tool Co., Ltd.
A. H. Wilkes & Co.
William Allday & Co., Ltd.

23. Automatics
John Cashmore Ltd.

24. Automatic Screw Machines
Charles Churchill & Co., Ltd.

25. Automatic Multi-spindle

26. Automatic Vertical

27. Auto-turned Parts
The Coventry Victor Motor Co., Ltd.
L. H. Newton & Co., Ltd.
Pneumatic Components, Ltd.
Charles Richards & Sons
Rolls Razor, Ltd.
J. Stead & Co., Ltd.
Yarwood Ingram & Co., Ltd.

28. Balancing Machines (Dynamic)
Ferranti, Ltd.
Muir Machine Tools, Ltd.
The Sperry Gyroscope Co., Ltd.

29. Bandsaws
J. Beardshaw & Son, Ltd.
Edgar Allen & Co., Ltd.
Thos. Firth & John Brown, Ltd.

The New Fortuna Machine Co., Ltd.
Henry Rossell & Co., Ltd.
J. Sagar & Co., Ltd
Spear & Jackson, Ltd.
Wilson Bros. (Leeds), Ltd.

30. Bar and Pipe Bending
Henry Berry & Co., Ltd.
Commercial Structures, Ltd.
R. K. Dundas, Ltd
Fielding & Platt, Ltd.
G. Johnson Bros.
Scottish Machine Tool Corporation, Ltd.
Charles Taylor (Birm.), Ltd.
Tipsy Aircraft Co., Ltd.
The Wadley Manufacturing Co., Ltd.
A. H. Wilkes & Co.

31. Bar Straightening Machines
Henry Berry & Co, Ltd.
Joshua Bigwood & Son, Ltd.
E.M.B. Co., Ltd.
Fielding & Platt, Ltd.
W. H. A. Robertson & Co., Ltd
Scottish Machine Tool Corporation, Ltd.
The Hydraulic Engineering Co., Ltd.

32. Bearings (Ball and Roller)
British Timken, Ltd.
Cooper Roller Bearings Co, Ltd
Delco-Remy & Hyatt, Ltd
Ransome & Marles Bearing Co., Ltd.
George Salter & Co., Ltd
Taylor & Wilson, Ltd
A. Warden & Co, Ltd.
Frank Wigglesworth & Co, Ltd

33. Bearings (Plain)
British Tyre & Rubber Co., Ltd
J. Burns, Ltd.
The Bushing Co, Ltd.
Silentbloc Ltd.
A. Warden & Co., Ltd.
Frank Wigglesworth & Co, Ltd.

34. Belting and Fasteners
George Angus & Co., Ltd.
British Belting & Asbestos, Ltd.
British Tyre & Rubber Co, Ltd.
James W. Carr & Co., Ltd.
S. T. Coburn & Son, Ltd.
J. H. Fenner & Co., Ltd.
Fleming, Birkby & Goodall, Ltd.
Francis W. Harris & Co, Ltd.
J. A. Harrison & Co. (Manchester) Ltd.
Richard Lloyd & Co., Ltd.
The North British Rubber Co., Ltd.
Penfold Fencing, Ltd.
Slip Products Co., Ltd.
Turner Brothers Asbestos Co, Ltd.
A. Warden & Co., Ltd.

35. Bending Machines
Henry Berry & Co., Ltd.
Joshua Bigwood & Son, Ltd.
S. T. Coburn & Son, Ltd.
Commercial Structures, Ltd.
F. J. Edwards, Ltd.
Hedleys, Ltd.
The Hydraulic Engineering Co., Ltd.
Keeton, Sons & Co., Ltd.
Scottish Machine Tool Corporation, Ltd.
Charles Taylor (Birm.), Ltd.
The Wadley Manufacturing Co., Ltd.

37. Blanking Machines
Greenwood Batley, Ltd.
Hedleys, Ltd.

38. Bolts, Nuts and Screws
Acton Bolt & Fine Threads, Ltd.
Aircraft Materials, Ltd.
S. T. Coburn & Son, Ltd.
Coventry Swaging Co., Ltd.
Morrisons Engineering, Ltd.
A. P. Newall & Co., Ltd.
L. H. Newton & Co., Ltd.
Charles Richards & Sons.
Simmonds Aerocessories, Ltd.
Taylor & Wilson, Ltd.

40. Boring and Drilling Machines
Adcock & Shipley, Ltd.
William Asquith, Ltd.
E. P. Barrus, Ltd.
John Cashmore, Ltd.
S. T. Coburn & Son, Ltd
E. H. Jones (Machine Tools), Ltd
H. W. Kearns & Co., Ltd
Kitchen & Wade, Ltd.
The Mortimer Engineering Co
Scottish Machine Tool Corporation, Ltd.

41. Boring and Facing Machines (Horizontal)
John Cashmore, Ltd.
H. W. Kearns & Co., Ltd.
Kitchen & Wade, Ltd.
Muir Machine Tools, Ltd
Scottish Machine Tool Corporation, Ltd.
D & J Tullis, Ltd.

43. Boring Machines for Metal
William Asquith, Ltd
Broadway Engineering Co., Ltd.
H. W. Kearns & Co., Ltd.
Kitchen & Wade, Ltd

44. Boring and Turning Mills
John Cashmore, Ltd.
Henry Rossell & Co., Ltd.
Webster & Bennett, Ltd.

45. Brakes
Automotive Products Co, Ltd.
Bendix, Ltd.
Dewhurst & Partner, Ltd
Dunlop Rubber Co., Ltd.
E M.B Co., Ltd.
New Hudson, Ltd.
The Palmer Tyre, Ltd.

46. Brake Linings
George Angus & Co., Ltd
British Belting & Asbestos, Ltd.
Dunlop Rubber Co, Ltd
Ferodo, Ltd.

47. Brass
The Alliance Foundry Co., Ltd.
The Delta Metal Co., Ltd.
I.C.I. Metals, Ltd.
W. H. A. Robertson & Co., Ltd.
Benjamin Whittaker, Ltd.
Wilbraham & Smith, Ltd.

48. Brass Finishing Machines
Charles Taylor (Birm.), Ltd.
Turner Machine Tools, Ltd.

49. Broaches
Coventry Gauge & Tool Co., Ltd.
Frank Heaver, Ltd.
The Mortimer Engineering Co.
Walter Spencer & Co., Ltd.
Peter Stubs, Ltd.
Weatherley Oilgear, Ltd.

50. Broaching Machines
John Cashmore, Ltd.
Coventry Gauge & Tool Co., Ltd
E.M.B. Co., Ltd.
Greenwood & Batley, Ltd.
Hopkinsons, Ltd.
Kendall & Gent (1920), Ltd.
Weatherley Oilgear, Ltd.

51. Bronze
The Delta Metal Co., Ltd.
W. H. A. Robertson & Co., Ltd.

53. Brushes
W. Canning & Co., Ltd.
S. T. Coburn & Son, Ltd.
Kleen-e-ze Brush Co., Ltd.
The Walpamur Co., Ltd.

54. Buffers
W. Canning & Co., Ltd.
The Hertfordshire Rubber Co, Ltd
Howells (Electric Motors), Ltd.
The Mortimer Engineering Co.
The North British Rubber Co., Ltd.

55. Cabin Heating
F. Corlett & Co., Ltd.
G. Johnson Bros
L. A. Rumbold & Co, Ltd.
Serck Radiators, Ltd

56. Cable Markers
D. H. Bonnella & Son, Ltd.
Hellermann Electric, Ltd.
E. Siegrist, Ltd.

57. Cable and Wire
Callender's Cable and Construction, Ltd.
Crompton Parkinson, Ltd.
Martin, Black & Co. (Wire Ropes) Ltd.
Rotax, Ltd.
Siemens Electric Lamps and Supplies, Ltd.

58. Canteens
Slip Products Co., Ltd
James Stott & Co. (Engineers), Ltd.

59. Canvas
Ernest Turner (London), Ltd.

60 Carpeting
Ernest Turner (London), Ltd.

61. Case-hardening Boxes
Kasenit, Ltd.
Darwins, Ltd
The National Steel Foundry (1914), Ltd

62. Case-hardening Compounds
W. Canning & Co, Ltd.
Fletcher Miller, Ltd.
G W B Electric Furnaces, Ltd.
Kasenit, Ltd.

63. Casting
The Alliance Foundry Co. Ltd.
Birmingham Aluminium Casting (1903) Co., Ltd.
John Dale, Ltd
Thos. Firth & John Brown, Ltd.
High Duty Alloys, Ltd.
Kent Alloys, Ltd.
The National Steel Foundry (1914), Ltd.
W. H. A. Robertson & Co., Ltd.

64. Castings (Die)
Birmingham Aluminium Casting (1903) Co., Ltd.
Die Casting Machine Tools, Ltd.
John Dale, Ltd.
Thos. Firth & John Brown, Ltd.
Firth-Vickers Stainless Steels, Ltd.
High Duty Alloys, Ltd.
Kent Alloys, Ltd.
Northern Aluminium Co., Ltd.
The Wolverhampton Die-Casting Co., Ltd.

65. Castings (Brass)
The Alliance Foundry Co., Ltd.
Chas. S. Madan & Co., Ltd.
W. H. A. Robertson & Co., Ltd.
S. Russell & Sons, Ltd.

66. Castings Iron (Light)
The Alliance Foundry Co., Ltd.
The British Piston Ring Co., Ltd.
Dartmouth Auto Castings, Ltd.
Joseph Evans & Sons (Wolverhampton), Ltd.
Ferranti, Ltd.
Hepworth & Grandage, Ltd.
Pneumatic Components, Ltd.
S. Russell & Sons, Ltd.

George Salter & Co., Ltd.
The Sheepbridge Stoke Centrifugal Castings Co., Ltd.
Suffolk Iron Foundry (1920), Ltd.
Taylor & Wilson, Ltd.
D. & J. Tullis, Ltd.

67. Castings Iron (Heavy)
The Alliance Foundry Co., Ltd.
Joshua Bigwood & Son, Ltd.
Davy & United Engineering Co., Ltd.
Joseph Evans & Sons (Wolverhampton), Ltd.
S. Russell & Sons, Ltd.
The Sheepbridge Stoke Centrifugal Castings Co., Ltd.
The United Steel Companies Ltd.,

68. Castings (Non-ferrous)
The Alliance Foundry Co., Ltd.
Birmingham Aluminium Casting (1903) Co., Ltd.
David Brown & Sons (Hudd.), Ltd.
Thos. Firth & John Brown, Ltd.
Kent Alloys, Ltd.
Chas. S. Madan & Co., Ltd.
Magnesium Castings & Products, Ltd.
Meigh High Tensile Alloys, Ltd.
Northern Aluminium Co., Ltd.
W. H. A. Robertson & Co., Ltd.
S. Russell & Sons, Ltd.
Short Brothers (Rochester and Bedford), Ltd.
D. & J. Tullis, Ltd.

69. Castings (Steel)
Edgar Allen & Co., Ltd.
Brown, Bayley's Steel Works, Ltd.
David Brown & Sons (Hudd.), Ltd.
The Clyde Alloy Steel Co., Ltd.
Thos. Firth & John Brown, Ltd.
Hopkinsons, Ltd.
Wm. Jessop & Sons, Ltd.
F. H. Lloyd & Co., Ltd.
The National Steel Foundry (1914), Ltd.
Samuel Osborn & Co., Ltd.

70. Cements (Aircraft)
Beetle Products Co., Ltd.
Docker Brothers
I.C.I. (Plastics), Ltd.
Lea Bridge Rubber Works, Ltd.
Slip Products Co.. Ltd.
Titanine, Ltd.
Ernest Turner (London), Ltd.
The Walpamur Co., Ltd.

71. Centering Machines
Adcock & Shipley, Ltd.
Kitchen & Wade, Ltd.
Turner Machine Tools, Ltd.

72. Centre Drills
E. P. Barrus, Ltd.
S. T. Coburn & Son, Ltd.
Thos. Firth & John Brown, Ltd.
Frank Heaver, Ltd.
Llewellin's Machine Co., Ltd.
Samuel Osborn & Co., Ltd.
Henry Rossell & Co., Ltd.

73. Centres (Lathe and Grinder)
S. T. Coburn & Son, Ltd.
S. Ralph Golding & Co., Ltd.
T. S. Harrison & Sons., Ltd.
Chas. S. Madan & Co., Ltd.
Samuel Osborn & Co., Ltd.
Pultra, Ltd.
Henry Rossell & Co., Ltd.
Wearden & Guylee, Ltd.

74. Centrifuges
British Twin Disc & Clarifiers, Ltd.
W. Canning & Co., Ltd.
Hopkinsons, Ltd.
Mellor Bromley & Co., Ltd.

75. Chain Drives
The Morse Chain Co., Ltd.

76. Chemicals
W. Canning & Co., Ltd.
Griffin & Tatlock, Ltd.

78. Chucks (Collet)
Broadway Engineering Co., Ltd.
Clare-Collets, Ltd.
Clarkson (Engineers), Ltd.
S. T. Coburn & Son, Ltd.
The Coventry Victor Motor Co., Ltd.
Hallam, Sleigh & Cheston
Hardinge Machine Tools, Ltd.
Pultra, Ltd.
Charles Taylor (Birm.), Ltd.
Wearden & Guylee, Ltd.

79. Chucks (Drill)
Edgar Allen & Co., Ltd.
Clare-Collets, Ltd.
S. T. Coburn & Son, Ltd.
The Coventry Victor Motor Co., Ltd.
Hallam, Sleigh & Cheston
Charles Taylor (Birm.), Ltd.
Wearden & Gyulee, Ltd.

80. Chucks (Lathe)
J. E. Baty & Co., Ltd.
John Cashmore, Ltd.
S. T. Coburn & Son, Ltd.
Charles Taylor (Birm.), Ltd.

81. Chucks (Magnetic)
S. T. Coburn & Son, Ltd.
J. H. Humphreys & Sons

83. Clamps
E. P. Barrus, Ltd.
T. Chatwin & Co.
S. T. Coburn & Son, Ltd.
Guyson Industrial Equipment, Ltd.
Speed Tools, Ltd.

84. Cleaning Cloth
Ernest Turner (London), Ltd.

85. Clutches (Friction and Centrifugal)
Automotive Products, Co., Ltd.
British Twin Disc & Clarifiers, Ltd.
J. H. Fenner & Co., Ltd.
Cooper Roller Bearings Co., Ltd.
Taylor Bros.
Whittaker, Hall & Co (1929), Ltd.
Frank Wigglesworth & Co., Ltd.

86. Cold Forgings
Magnesium Castings & Products, Ltd.
Rotherham Forge & Rolling Mills Co., Ltd.

87. Compressors (Air)
A.B.C. Motors, Ltd.
Aeraspray Manufacturing Co., Ltd.
Aerostyle, Ltd.
Broom & Wade, Ltd.
John Cashmore, Ltd.
S. T. Coburn & Son, Ltd.
The Coventry Victor Motor Co., Ltd.
Dobbie McInnes, Ltd.
E.M.B. Co., Ltd.
Joseph Evans & Sons (Wolverhampton), Ltd.
Pneumatic Components, Ltd.
Reavell & Co., Ltd.
Tangyes, Ltd.
Tilghman's Patent Sand Blast Co., Ltd.
Volspray, Ltd.
A. H. Wilkes & Co.

88. Compressor Unit
Broom & Wade, Ltd.
The Coventry Victor Motor Co., Ltd.
E.M.B. Co., Ltd.
Pneumatic Components, Ltd.
Reavell & Co., Ltd.
Volspray, Ltd.

90. Controls
Bell Punch Co., Ltd.
R. K. Dundas, Ltd.
Dunlop Rubber Co., Ltd.
Ether, Ltd.
Exactor Control, Ltd.
The Palmer Tyre, Ltd.
Rolls Razor, Ltd.
Simmonds Aerocessories, Ltd.
Taylor & Wilson, Ltd.
The S.S. White Co., of Great Britain, Ltd.

91. Control Boxes
J. Burns, Ltd.

92. Control Gear (Electric)
Airedale Electrical & Manufacturing Co., Ltd.
D. H. Bonnella & Son, Ltd.
Brookhirst Switchgear, Ltd.
Crompton Parkinson, Ltd.
Dewhurst & Partner, Ltd.
E.M.B. Co., Ltd.
Ivo Engineering & Construction Co., Ltd.
Londex, Ltd.
Metropolitan-Vickers Electrical Co., Ltd.
Midland Electric Manufacturing Co., Ltd.
R. B. Pullin & Co., Ltd.
Rotax, Ltd.
The British Thermostat Co., Ltd.
The English Electric Co., Ltd.
Waymouth Gauges & Instruments, Ltd.

93. Control Switches
Avimo, Ltd.
D. H. Bonnella & Son, Ltd.
Brookhirst Switchgear, Ltd.
Dewhurst & Partner, Ltd.
E.M.B. Co., Ltd.
Londex, Ltd.
Rotax, Ltd.
The British Thermostat Co., Ltd.
Metropolitan-Vickers Electrical Co., Ltd.
Waymouth Gauges & Instruments, Ltd.

93a. Conveyors
Geo. W. King, Ltd.

94. Cooking Equipment
Siemens Electric Lamps and Supplies, Ltd.
James Stott & Co. (Engineers), Ltd.
The English Electric Co., Ltd.

95. Coolers
A. Kershaw & Sons, Ltd.
Serck Radiators, Ltd.
The Visco Engineering Co., Ltd.

96. Copper
I.C.I. Metals, Ltd.
Wilbraham & Smith, Ltd.

97. Copper (Bar)
The Delta Metal Co., Ltd.
I.C.I. Metals, Ltd.
Wilbraham & Smith, Ltd.

98. Copper (Sheet)
I.C.I. Metals, Ltd.
Wilbraham & Smith, Ltd.

99. Copper (Tubing)
I.C.I. Metals, Ltd.
Wilbraham & Smith, Ltd.

100. Copper (Wire and Cable
I.C.I. Metals, Ltd.
Wilbraham & Smith, Ltd.

101. Cork
Coopers Mechanical Joints, Ltd.

102. Couplings
Avimo, Ltd.
British Ermeto Corporation, Ltd
The Hertfordshire Rubber Co., Ltd.
Metalastik, Ltd.

The Morse Chain Co., Ltd.
A. Schrader's Son
Silentbloc, Ltd.
A. Warden & Co., Ltd.
Frank Wigglesworth & Co., Ltd.

103. Cutting Alloys
Edgar Allen & Co., Ltd.
Thos. Firth & John Brown, Ltd.
Wm. Jessop & Sons, Ltd.
Samuel Osborn & Co., Ltd.
The Rennie Tool Co., Ltd.
J. J. Saville & Co., Ltd.

104. Cutting Metals
Edgar Allen & Co., Ltd.
Samuel Osborn & Co., Ltd.

105. Cutters (Gear)
David Brown & Sons (Hudd.), Ltd.
Thos. Firth & John Brown, Ltd.
S. Ralph Golding & Co., Ltd.
Frank Heaver, Ltd.
J. Parkinson & Son
Henry Rossell & Co., Ltd.
Henry Simon, Ltd.
Walter Spencer & Co., Ltd.

106. Cutters (Milling)
Edgar Allen & Co., Ltd.
Arnott & Harrison, Ltd.
J. Beardshaw & Son, Ltd.
James W. Carr & Co., Ltd.
T. Chatwin & Co.
Charles Churchill & Co., Ltd.
Clare-Colletts, Ltd.
Coventry Gauge & Tool Co., Ltd.
Thos. Firth & John Brown, Ltd.
S. Ralph Golding & Co., Ltd.
Hallam, Sleigh & Cheston
Frank Heaver, Ltd.
Kendall & Gent (1920), Ltd.
Llewellin's Machine Co., Ltd.
Richard Lloyd & Co., Ltd.
B. O. Morris, Ltd.
Samuel Osborn & Co., Ltd.
Ratcliffe Tool Co., Ltd.
Henry Rossell & Co., Ltd.
Walter Spencer & Co., Ltd.
Wm. Ward & Son (Sheffield), Ltd.

107. Cutting-off Machines
L. J. H. Ballinger
Broadway Engineering Co., Ltd.
J. Sagar & Co., Ltd.
Charles Taylor (Birm.), Ltd.
Voucher, Ltd.

108. Cutting Compound
Fletcher Miller, Ltd.
Slip Products Co., Ltd.

109. Covers (Aircraft)
Lea Bridge Rubber Works, Ltd.
L. A. Rumbold & Co., Ltd.
Tipsy Aircraft Co., Ltd.
Ernest Turner (London), Ltd.
Weathershields, Ltd.

110. Cowling Fasteners
Oddie Fasteners
Presswork Products, Ltd.
Simmonds Aerocessories, Ltd.

111. Crankshafts
Ambrose Shardlow & Co., Ltd.
The Coventry Victor Motor Co., Ltd.
Thos. Firth & John Brown, Ltd.
Wm. Jessop & Sons, Ltd.
Laystall Engineering Co., Ltd.

112. Cutouts
D. H. Bonnella & Son, Ltd.
Waymouth Gauges & Instruments, Ltd.

113. Degreasers
Bratby & Hinchliffe, Ltd.
S. T. Coburn & Son, Ltd.
Ivo Engineering & Construction Co., Ltd.
Slip Products Co., Ltd.
Titanine, Ltd.

114. Degreasing Compound
W. Canning & Co., Ltd.
R. K. Dundas, Ltd.
Fletcher Miller, Ltd.
Slip Products Co., Ltd.
Titanine, Ltd.

115. De-icing Pumps
Dunlop Rubber Co., Ltd.
Rotax, Ltd.

115a. Demagnetisers
J. H. Humphreys & Sons

116. Diamond Dressers (Grinding Wheels)
The Anglo Abrasive Works, Ltd.
S. T. Coburn & Son, Ltd.
S. L. Van Moppes

117. Diamond Tools for Abrasive Wheel Turning
S. T. Coburn & Son, Ltd.
S. L. Van Moppes

118. Diamond Tipped Cutting Tools
S. T. Coburn & Son, Ltd.
S. L. Van Moppes

119. Diamond Indenters
S. L. Van Moppes

120. Diamond Powder
S. L. Van Moppes

121. Die Casting
Die Casting Machine Tools, Ltd.
Dyson & Co., Enfield (1919), Ltd.
Kent Alloys, Ltd.
Magnesium Castings & Products, Ltd.
Northern Aluminium Co., Ltd.
Wilmot-Breeden, Ltd.
The Wolverhampton Die Casting Co., Ltd.

122. Die Casting Machines
Die Casting Machine Tools, Ltd.
E.M.B. Co., Ltd.

123. Die-Heads
Voucher, Ltd.

124. Die Sinking Machines
Broadway Engineering Co., Ltd.
Taylor, Taylor & Hobson, Ltd.

125. Dinghies
Dunlop Rubber Co., Ltd.
Lea Bridge Rubber Works, Ltd.
Merron, Ltd.
Oddie Fasteners
Saro Laminated Wood Products, Ltd.
Veneercraft, Ltd.

126. Dividing Heads
John Cashmore, Ltd.
Coventry Gauge & Tool Co., Ltd.
B. O. Morris, Ltd.
J. Parkinson & Son
Tom Senior
Taylor, Taylor & Hobson, Ltd.

127. Dope
Cellon, Ltd.
Docker Bros.
Titanine, Ltd.
The Walpamur Co., Ltd.

128. Drafting Machines
Hall Harding, Ltd.
Harper & Tunstall, Ltd.

129. Drawing Office Equipment
Hall Harding, Ltd.
Harper & Tunstall, Ltd.
Ozalid Co., Ltd.
A.R.P. Plansafes & Millennium Planfile Co.
A. G. Thornton, Ltd.
E. R. Watts & Son, Ltd.

130. Drill Sleeves and Sockets
Edgar Allen & Co., Ltd.
E. P. Barrus, Ltd.
T. Chatwin & Co.
S. T. Coburn & Son, Ltd.
The Coventry Victor Motor Co., Ltd.
Kitchen & Wade, Ltd.
Llewellin's Machine Co., Ltd.
Samuel Osborn & Co., Ltd.
Henry Rossell & Co., Ltd.
Wearden & Guylee, Ltd.

131. Drills (Twist)
Edgar Allen & Co., Ltd.
J. Beardshaw & Son, Ltd.
James W. Carr & Co., Ltd.
T. Chatwin & Co.
Charles Churchill & Co., Ltd.
S. T. Coburn & Son, Ltd.
Thos. Firth & John Brown, Ltd.
Samuel Osborn & Co., Ltd.
Henry Rossell & Co., Ltd.
J. Sagar & Co., Ltd.
Walter Spencer & Co., Ltd.
Peter Stubs, Ltd.
Turton Brothers & Matthews, Ltd
Wearden & Guylee, Ltd.

132. Drilling Bushes
Bolton Engineering Co., Ltd.
S. T. Coburn & Son, Ltd.
The Norbury Engineering Co., Ltd.
Henry Rossell & Co., Ltd.
B. J. & J. Silcom
Talbot Tool Co., Ltd.

133. Drilling Machines (Multi-spindle)
Adcock & Shipley, Ltd.
William Asquith, Ltd.
John Cashmore, Ltd.
S. T. Coburn & Son, Ltd.
Kitchen & Wade, Ltd.
Fredk. Town & Sons

134. Drilling Machines (Bench)
Adcock & Shipley, Ltd.
Broadway Engineering Co., Ltd.
John Cashmore, Ltd.
Charles Churchill & Co., Ltd.
S. T. Coburn & Son, Ltd.
Grafton Tools, Ltd.
T. S. Harrison & Sons, Ltd.
Hedleys, Ltd.
A. Kershaw & Sons, Ltd.
The Mortimer Engineering Co.

135. Drilling Machines (Radial)
Adcock & Shipley, Ltd.
William Asquith, Ltd.
E. P. Barrus, Ltd.
John Cashmore, Ltd.
Kitchen & Wade, Ltd.
D. Mitchell & Co., Ltd.
Fredk. Town & Sons

136. Drilling Machines (Sensitive and Automatic)
Adcock & Shipley, Ltd.
William Asquith, Ltd.
John Cashmore, Ltd.
Hedleys, Ltd.
A. Kershaw & Sons, Ltd.
Kitchen & Wade, Ltd.
The Mortimer Engineering Co.
Fredk. Town & Sons

137. Drilling Machines (Vertical)
Adcock & Shipley, Ltd.
William Asquith, Ltd.
Broadway Engineering Co., Ltd.
F. J. Edwards, Ltd.
Hedleys, Ltd.
Kitchen & Wade, Ltd.
The Mortimer Engineering Co.
Fredk. Town & Sons

138. Drilling Machines (Universal and Portable)
William Asquith, Ltd.
S T. Coburn & Son, Ltd.
Kitchen & Wade, Ltd.
Fredk. Town & Sons
S. Wolf & Co., Ltd.

139. Dynamometers
Cambridge Instrument Co., Ltd.
The English Electric Co., Ltd.
Heenan & Froude, Ltd.

Laurence, Scott & Electromotors, Ltd.
George Salter & Co., Ltd.

140. Dynamotors
The English Electric Co., Ltd.
Frank Heaver, Ltd.

140a. Electric Cables
Callender's Cable & Construction, Ltd.

141. Electric Etching
W. Canning & Co., Ltd.
Griffin & Tatlock, Ltd.

142. Electric Steel
Edgar Allen & Co., Ltd.
Thos. Firth & John Brown, Ltd.
Wm. Jessop & Sons, Ltd.
The National Steel Foundry (1914), Ltd.
J. J. Saville & Co., Ltd.
Spear & Jackson, Ltd.

143. Electric Tools
E. P. Barrus, Ltd.
B. O. Morris, Ltd.
S. Wolf & Co., Ltd.
S. Ralph Golding & Co., Ltd.

144. Enamel
Docker Brothers
Titanine, Ltd.
The Walpamur Co., Ltd.

144a. Endless Belts for Short Centre Drives
British Belting & Asbestos, Ltd.

145. Engine Instruments
Cambridge Instrument Co., Ltd.
Dobbie McInnes, Ltd.
Elliott Brothers (London), Ltd.
Negretti & Zambra
Sangamo Weston, Ltd.
Short & Mason, Ltd.
The British Thermostat Co., Ltd.

146. Engine Testing Plant
L. J. H. Ballinger
George H. Elt, Ltd.
Heenan & Froude, Ltd.
Laurence, Scott & Electromotors, Ltd.

147. Engraving Machines
S. T. Coburn & Son, Ltd.
The New Fortuna Machine Co., Ltd.
Tom Senior
Taylor, Taylor & Hobson, Ltd.

148. Etching Equipment
W. Canning & Co., Ltd.
Griffin & Tatlock, Ltd.
Taylor, Taylor & Hobson, Ltd.

148a. Exhaust Manifolds
The Bristol Aeroplane Co., Ltd.
Thompson Brothers (Bilston), Ltd.

149. Fabric
Ernest Turner (London), Ltd.

149a. Factory Equipment
Sankey-Sheldon

150. Felt
W. Canning & Co., Ltd.
J. A. Harrison & Co. (Manchester), Ltd.
B. O. Morris, Ltd.
Ernest Turner (London), Ltd.

151. Fibre Board
J. Burns, Ltd.
Coopers Mechanical Joints, Ltd.
James Latham, Ltd.

152. Fibre (Vulcanised)
J. Burns, Ltd.
M. & B. Plastics, Ltd.

153. Files
Edgar Allen & Co., Ltd.
E. P. Barrus, Ltd.
J. Beardshaw & Son, Ltd.
James W. Carr & Co., Ltd.
T. Chatwin & Co.
Charles Churchill & Co., Ltd.
Darwins, Ltd.
Thos. Firth & John Brown, Ltd.
Hobson, Houghton & Co., Ltd.
B. O. Morris, Ltd.
Samuel Osborn & Co., Ltd.
Henry Rossell & Co., Ltd.
J. J. Saville & Co., Ltd.
Walter Spencer & Co., Ltd.
Peter Stubs, Ltd.

154. Filing and Sawing Machines
S. T. Coburn & Son, Ltd.
Thos. Firth & John Brown, Ltd.
Henry Milnes, Ltd.
B. O. Morris, Ltd.
The Mortimer Engineering Co.
S. Wolf & Co., Ltd.

155. Filters
Air-Maze (Great Britain), Ltd.
Automotive Products, Co., Ltd.
Bratby & Hinchliffe, Ltd.
British Twin Disc & Clarifiers, Ltd.
Coopers Mechanical Joints, Ltd.
Pneumatic Components Ltd.
Stream-Line Filters, Ltd.
The Visco Engineering Co., Ltd.

156. Finishes
Docker Brothers
Titanine, Ltd.
The Walpamur Co., Ltd.

157. Finishing Machines
Broadway Engineering Co., Ltd.

158. Fins
Morrisons Engineering, Ltd.
Tipsy Aircraft Co., Ltd.

159. Fire-Extinguishing Equipment
George Angus & Co., Ltd.
Coventry Climax Engines, Ltd.
General Fire Appliance Co., Ltd.
Graviner Manufacturing Co., Ltd.

160. Fixtures
Arnott & Harrison, Ltd.
Broadway Engineering Co., Ltd.
R. K. Dundas, Ltd.
Hallam, Sleigh & Cheston
Hilbert & Whitwam, Ltd.
Leytonstone Jig & Tool Co., Ltd.
Monarch Tool Co., Ltd.
The Norbury Engineering Co., Ltd.
Alfred Partridge & Co., Ltd.

161. Flaps
George H. Elt, Ltd.
Morrisons Engineering, Ltd.
Necaco, Ltd.
Taylor & Wilson, Ltd.
Tipsy Aircraft Co., Ltd.

162. Flap-Jacks
Automotive Products Co., Ltd.
The British Thermostat Co., Ltd.

163. Flexible Shafts
S. T. Coburn & Son, Ltd.
F. Gilman (B.S.T.), Ltd.
B. O. Morris, Ltd.
A. Warden & Co., Ltd.
The S.S. White Co., of Great Britain, Ltd.

163a. Flexible Drives
F. Gilman (B.S.T.), Ltd.
B. O. Morris, Ltd.

163b. Flexible Drive Equipment
F. Gilman (B.S.T.), Ltd.

163c. Flexible Shaft Equipment
B. O. Morris, Ltd.

164. Flooring (Aircraft)
The Aeronautical & Panel Plywood Co., Ltd.
The Hertfordshire Rubber Co., Ltd.
Morrisons Engineering, Ltd.
Simmonds Aerocessories, Ltd.
Ernest Turner (London), Ltd.

165. Floor Grinders (High Speed)
T. S. Harrison & Sons, Ltd.
Turner Machine Tools, Ltd.

166. Flowmeters
Elliott Brothers (London), Ltd.
Griffin & Tatlock, Ltd.
Rotameter Manufacturing Co., Ltd.
Short & Mason, Ltd.

167. Flux
W. Canning & Co., Ltd.
F. A. Hughes & Co., Ltd.
A. Warden & Co., Ltd.

168. Flying Boats
Short Brothers (Rochester & Bedford), Ltd.

169. Forgings
Edgar Allen & Co., Ltd.
Birmetals, Ltd.
Brown, Bayley's Steel Works, Ltd.
The Clyde Alloy Steel Co., Ltd.
Thos. Firth & John Brown, Ltd.
Hattersley & Ridge, Ltd.
Light-Metal Forgings, Ltd.
Magnesium Castings & Products, Ltd.
Northern Aluminium Co., Ltd.
Samuel Osborn & Co., Ltd.
Quick Supply, Ltd.
Charles Richards & Sons
Henry Rossell & Co., Ltd.
Rotherham Forge & Rolling Mills Co., Ltd.
Walter Spencer & Co., Ltd.
The United Steel Companies Ltd.
T. Williams' Tilton Road Works, Ltd.

170. Forging Machines
Eumuco (England), Ltd.
Greenwood & Batley, Ltd.

171. Forging Rolls
Eumuco (England), Ltd.
Thos. Firth & John Brown, Ltd.
W. H. A. Robertson & Co., Ltd.

172. Free Cutting Steel
Colvilles, Ltd.
The Clyde Alloy Steel Compies Ltd.
Thos. Firth & John Brown, Ltd.
Wm. Jessop & Sons, Ltd.
Samuel Osborn & Co., Ltd.
Charles Richards & Sons
Henry Rossell & Co., Ltd.
J. J. Saville & Co., Ltd.
The United Steel Co's., Ltd.

173. Fuel Contents Gauges
Simmonds Aerocessories, Ltd.

174. Fuel Pumps
Avimo, Ltd.
Joseph Evans & Sons (Wolverhampton), Ltd.
Rotax, Ltd.

175. Furnaces (Heat Treatment)
Alldays & Onions, Ltd.
British Furnaces, Ltd.
Controlled Heat and Air, Ltd.
G. W. B. Electric Furnaces, Ltd.
Ferranti, Ltd.
Incandescent Heat Co., Ltd.
Ivo Engineering & Construction Co., Ltd.
Kasenit, Ltd.
Serck Radiators, Ltd.
Th. Teisen
The Wellman Smith-Owen Engineering Corporation, Ltd.

176. Fuses
D. H. Bonnella & Son, Ltd.
The English Electric Co., Ltd.

176a. Fuses (Electrical)
Midland Electric Manufacturing Co., Ltd.

177. Gaskets
British Tyre & Rubber Co., Ltd.
Coopers Mechanical Joints, Ltd.
J. A. Harrison & Co. (Manchester) Ltd.
The Hertfordshire Rubber Co., Ltd
Harold Jackson, Ltd.
Richard Klinger, Ltd.
The North British Rubber Co., Ltd.
Turner Brothers Asbestos Co., Ltd.

177a. Gasket Cutting Machines
The Sheridan Machinery Co., Ltd.

178. Gauges (Measuring)
Arnott & Harrison, Ltd.
E. P. Barrus, Ltd.
J. E. Baty & Co., Ltd.
Bolton Engineering Co., Ltd.
Broadway Engineering Co., Ltd.
Coventry Gauge & Tool Co, Ltd
The Coventry Movement Co., Ltd.
Crclt Engineering, Ltd.
R. K. Dundas, Ltd.
Gay's (Hampton), Ltd.
S. Ralph Golding & Co., Ltd.
Gratton Tools, Ltd.
Huddersfield Gauges, Ltd
E. H. Jones (Machine Tools), Ltd.
J. Martin & Sons, Ltd.
Monarch Tool Co., Ltd.
The Norbury Engineering Co., Ltd.
The Pilot Plug Gauge Co., Ltd.
Pitter Gauge & Precision Tool Co.
R. B. Pullin & Co., Ltd.
Ratcliffe Tool Co., Ltd.
B. J. & J. Silcom
Simmonds Aerocessories, Ltd.
Small Tools, Ltd.
Solex, Ltd.
The Truform Gauge Co., Ltd.
Turner Machine Tools, Ltd.
Voucher, Ltd.

179. Gauges (Pressure)
Cambridge Instrument Co., Ltd.
David Harcourt, Ltd.
Dobbie McInnes, Ltd.
Hopkinsons, Ltd
Negretti & Zambra
Pneumatic Components, Ltd.
A. Schrader's Son
George Salter & Co., Ltd.
Short & Mason, Ltd.
Waymouth Gauges & Instruments, Ltd.
Edward Wilcox & Co., Ltd.

180. Gauges (Vacuum)
Cambridge Instrument Co., Ltd.
David Harcourt, Ltd.
Dobbie McInnes, Ltd.
Hopkinsons, Ltd.
George Salter & Co., Ltd.
Short & Mason, Ltd.
The Sperry Gyroscope Co., Ltd.
Waymouth Gauges & Instruments, Ltd.

181. Gears
A.B.C. Motors, Ltd.
George Angus & Co., Ltd.
David Brown & Sons (Hudd.), Ltd.
The Coventry Victor Motor Co., Ltd.
S. Ralph Golding & Co., Ltd.
Llewellin's Machine Co., Ltd.
The Motor Gear & Engineering Co., Ltd.
Alfred Wiseman & Co., Ltd.

182. Gear Cutting Machines
David Brown & Sons (Hudd.), Ltd.
John Cashmore, Ltd.
J. Parkinson & Son
Henry Simon, Ltd.

183. Gear Testers
J. Parkinson & Son

184. Gear Hobbing Machines
David Brown & Sons (Hudd.) Ltd.
Muir Machine Tools, Ltd.

185. Gear Units (Reduction and Variable Speed)
Broadway Engineering Co, Ltd.
David Brown & Sons (Hudd.), Ltd.
The Coventry Victor Motor Co., Ltd.
Llewellin's Machine Co., Ltd.
Henry Simon, Ltd.
A. Warden & Co., Ltd.
Alfred Wiseman & Co., Ltd.

186. Gearing (Speed Reduction)
George Angus & Co., Ltd.
David Brown & Sons (Hudd.), Ltd.
Llewellin's Machine Co., Ltd.
The Motor Gear & Engineering Co., Ltd.
Henry Simon, Ltd.
A. Warden & Co., Ltd.
Alfred Wiseman & Co., Ltd.

187. Gearing Spur (Machine Cut)
George Angus & Co., Ltd.
David Brown & Sons (Hudd.), Ltd.
S. Ralph Golding & Co., Ltd.
Llewellin's Machine Co., Ltd.
Muir Machine Tools, Ltd.
Joshua Bigwood & Son, Ltd.
The Motor Gear & Engineering Co., Ltd.
Henry Simon, Ltd.
Alfred Wiseman & Co., Ltd.

188. Gearing Worm (Machine Cut)
George Angus & Co., Ltd.
David Brown & Sons (Hudd.), Ltd.
S. Ralph Golding & Co., Ltd.
Llewellin's Machine Co., Ltd.
The Motor Gear & Engineering Co, Ltd.
Henry Simon, Ltd.
Alfred Wiseman & Co., Ltd.

189. Gear Units (Variable Speed)
David Brown & Sons (Hudd.), Ltd.
Greenwood & Batley, Ltd.
E. H. Jones (Machine Tools), Ltd.
Llewellin's Machine Co., Ltd.
The Motor Gear & Engineering Co., Ltd.
A. Warden & Co., Ltd.
Frank Wigglesworth & Co., Ltd.
Alfred Wiseman & Co., Ltd.

190. Generators
John Cashmore, Ltd.
Crompton Parkinson, Ltd.
Douglas (Kingswood), Ltd.
Laurence, Scott & Electromotors, Ltd.
Metropolitan-Vickers Electrical Co., Ltd.
Bruce Peebles & Co., Ltd.
Photowork, Ltd.
Rotax, Ltd.
The English Electric Co., Ltd.

191. Gill Motors
The British Thermostat Co., Ltd.

192. Glass
Dufalite, Ltd.
"Triplex" Safety Glass Co., Ltd.

193. Glues
Aero Research, Ltd.
Beetle Products Co., Ltd.
W. Canning & Co., Ltd.
Lactocol, Ltd.
Ernest Turner (London), Ltd.

193a. Graphite (Colloidal)
E. G. Acheson, Ltd.

194. Grinding Machines (Bench)
E. P. Barrus, Ltd.
Broadway Engineering Co., Ltd.
W. Canning & Co., Ltd.
S. T. Coburn & Son, Ltd.
Commercial Structures, Ltd.
S. Ralph Golding & Co., Ltd.
T. S. Harrison & Sons, Ltd.
Howells (Electric Motors), Ltd.
The Mortimer Engineering Co
S. Wolf & Co., Ltd.

195. Grinding Machines (Carbide Tools)
Broadway Engineering Co., Ltd.
S. Ralph Golding & Co, Ltd.
T. S Harrison & Sons, Ltd.

196. Grinding Machines (Centreless)
Turner Machine Tools, Ltd.

197. Grinding Machines (Cylindrical)
Broadway Engineering Co., Ltd.
John Cashmore, Ltd.
Coventry Gauge & Tool Co., Ltd.
F. J. Edwards, Ltd.
E. H. Jones (Machine Tools), Ltd.
G. T. Sharp

198. Grinding Machines (Disc)
W. Canning & Co., Ltd.
John Cashmore, Ltd.
Geo. Jackman Machine Tool Co., Ltd.
Tom Senior
Turner Machine Tools, Ltd.

199. Grinding Machines (H.S.S. Tools)
S. Ralph Golding & Co., Ltd.
T. S. Harrison & Sons, Ltd.

200. Grinding Machines, (Internal)
James W. Carr & Co., Ltd
S. Ralph Golding & Co., Ltd.
G. T. Sharp

201. Grinding Machines (Precision)
Broadway Engineering Co., Ltd
S. Ralph Golding & Co., Ltd.
G. T. Sharp

202. Grinding Machines (Surface)
Broadway Engineering Co., Ltd.
John Cashmore, Ltd.
S. T. Coburn & Son, Ltd.
Turner Machine Tools, Ltd.
Voucher, Ltd.

203. Grinding Machines (Thread)
Coventry Gauge & Tool Co., Ltd.

204. Grinding Machines (Tool and Cutter)
Broadway Engineering Co., Ltd.
S. T. Coburn & Son, Ltd.
Coventry Gauge & Tool Co., Ltd.
The Coventry Victor Motor Co., Ltd.
Kendall & Gent (1920), Ltd.
Voucher, Ltd.

205. Grinding Machines (Worm Thread)
David Brown & Sons (Hudd.), Ltd.

206. Grinders (Tool Post)
E. P. Barrus, Ltd.
S. Ralph Golding & Co., Ltd.
Pultra, Ltd.
S. Wolf & Co., Ltd.

207. Grinding Wheels
The Anglo Abrasive Works, Ltd.

Charles Churchill & Co., Ltd.
S. T. Coburn & Son, Ltd.
S. Ralph Golding & Co., Ltd.
Richard Lloyd & Co., Ltd.
Norton Grinding Wheel Co., Ltd.

208. Guillotine Blades
Darwins, Ltd.
Keeton, Sons & Co., Ltd.
Henry Rossell & Co., Ltd.
Turton Brothers & Matthews, Ltd

209. Guillotines
Joshua Bigwood & Son, Ltd.
John Cashmore, Ltd.
F. J. Edwards, Ltd.
Greenwood & Batley, Ltd.
Keeton, Sons & Co., Ltd.
W. H. A. Robertson & Co., Ltd.
The Wadley Manufacturing Co., Ltd.

210. Hack-saw Blades
Edgar Allen & Co., Ltd.
E. P. Barrus, Ltd.
Charles Baynes, Ltd.
J. Beardshaw & Son, Ltd.
James W. Carr & Co., Ltd.
Charles Churchill & Co., Ltd.
S. T. Coburn & Son, Ltd.
Darwins, Ltd.
Thos. Firth & John Brown, Ltd.
S. Ralph Golding & Co., Ltd.
Morris & Ingram
The New Fortuna Machine Co., Ltd.
Samuel Osborn & Co., Ltd.
J. W. C. H. Platt, Ltd.
Henry Rossell & Co., Ltd.
Spear & Jackson, Ltd.
Peter Stubs, Ltd.

211. Hack-saw Machines
Broadway Engineering Co., Ltd.
John Cashmore, Ltd.
T. Chatwin & Co.
S. T. Coburn & Son, Ltd.
The Coventry Victor Motor Co., Ltd.
F. J. Edwards, Ltd.
The New Fortuna Machine Co., Ltd.

212. Hammers (Pneumatic)
Alldays & Onions, Ltd.
Broom & Wade, Ltd.
John Cashmore, Ltd.
Eumuco (England), Ltd.
John Macdonald & Co. (Pneumatic Tools), Ltd.

213. Hand-tools
Aircraft Materials, Ltd.
E. P. Barrus, Ltd.
Charles Churchill & Co., Ltd.
S. T. Coburn & Son, Ltd.
Hallam, Sleigh & Cheston
Jenks Brothers, Ltd.
Leytonstone Jig & Tool Co., Ltd.
J. Martin & Sons, Ltd.
B. O. Morris, Ltd.
Samuel Osborn & Co., Ltd.
Henry Rossell & Co., Ltd.
M. Semet & Co., Ltd.
Peter Stubs, Ltd.
The Wadley Manufacturing Co., Ltd.
T. Williams' Tilton Road Works, Ltd.

213a. Hand-Tools (Pliers, Nippers, etc.)
Elliott-Lucas, Ltd.

214. Hangar Doors
Geo. W. King, Ltd.
S. Grahame Ross, Ltd.

215. Hardness Gauges
Broadway Engineering Co., Ltd.
Griffin & Tatlock, Ltd.

216. Harness (Ignition)
Lodge Plugs, Ltd.
Marconi's Wireless Telegraph Co., Ltd.
Rotax, Ltd.

217. Harness (Safety Equipment)
L. A. Rumbold & Co., Ltd.

218. Heating (Aircraft)
British Trane Co., Ltd.
G. Johnson Bros.
Serck Radiators, Ltd.

219. Heating and Ventilating Equipment
Aeraspray Manufacturing Co., Ltd.
Air-Maze (Great Britain), Ltd.
Airscrew Co., Ltd.
The British Rototherm Co., Ltd.
The British Thermostat Co., Ltd.
British Trane Co., Ltd.
Controlled Heat & Air, Ltd.
J. Gardner & Co., Ltd.
Ivo Engineering & Construction Co., Ltd.
Mellor Bromley & Co., Ltd.
Serck Radiators, Ltd.
Spencer & Halstead, Ltd
The Visco Engineering Co., Ltd.

220. Heat-resisting Steels
Edgar Allen & Co., Ltd.
J. Beardshaw & Son, Ltd.
Brown, Bayley's Steel Works, Ltd.
The Clyde Alloy Steel Co., Ltd.
Colvilles, Ltd.
Darwins, Ltd.
Samuel Osborn & Co., Ltd.
Walter Spencer & Co., Ltd.
The United Steel Co's., Ltd.

221. Honers
Kitchen & Wade, Ltd.
Morris & Ingram

222. Hoods
J. Gardner & Co., Ltd.
Ivo Engineering & Construction Co., Ltd.
Plastilume Products, Ltd.
L. A. Rumbold & Co., Ltd.
Tipsy Aircraft Co., Ltd.
Ernest Turner (London), Ltd.
Weathershields, Ltd.

223. Hose
Acetylene Generator & Tool Co., Ltd.
Aeraspray Manufacturing Co., Ltd.
Aircraft Materials, Ltd.
George Angus & Co., Ltd.
Automotive Products Co., Ltd.
British Tyre & Rubber Co., Ltd.
Dunlop Rubber Co., Ltd.
J. H. Fenner & Co., Ltd.
J. A. Harrison & Co. (Manchester), Ltd.
The Hertfordshire Rubber Co., Ltd.
The Ioco Rubber & Waterproofing Co., Ltd.
The North British Rubber Co., Ltd.
The Palmer Tyre, Ltd.
Volspray, Ltd.
Wilkinson Rubber Linatex, Ltd.

224. Hose Clips
Acetylene Generator & Tool Co., Ltd.
Aeraspray Manufacturing Co., Ltd.
Aircraft Materials, Ltd.
George Angus & Co., Ltd.
D. H. Bonnella & Son, Ltd.
S. T. Coburn & Son, Ltd.
Volspray, Ltd.

225. Hydraulic Equipment
George Angus & Co., Ltd.
Automotive Products Co., Ltd.
L. J. H. Ballinger
Henry Berry & Co., Ltd.
Joshua Bigwood & Son, Ltd.
The British Thermostat Co., Ltd.
Connolly Bros. (Curriers), Ltd
Davy and United Engineering Co., Ltd.
Fielding & Platt, Ltd.
Greenwood & Batley, Ltd.
The Hydraulic Engineering Co., Ltd.
Pump Unit, Ltd.
S. Grahame Ross, Ltd.
Towler Brothers (Patents), Ltd.
Weatherley Oilgear, Ltd.

226. Hydraulic Equipment (Aircraft)
Automotive Products Co., Ltd.
Bell Punch Co., Ltd.
Joshua Bigwood & Son, Ltd.
The British Thermostat Co., Ltd.
The Palmer Tyre, Ltd.
The Sperry Gyroscope Co., Ltd.

227. Hydraulic Fluids
Automotive Products Co., Ltd.
Pump Unit, Ltd.
The Sperry Gyroscope Co., Ltd.
Titanine, Ltd.

228. Hydraulic Leathers
George Angus & Co., Ltd.
Henry Berry & Co., Ltd.
Fielding & Platt, Ltd.
J. A. Harrison & Co. (Manchester), Ltd.
Pneumatic Components, Ltd.

229. Identification Tape
Hellermann Electric, Ltd.
Herts Pharmaceuticals, Ltd.
Industrial Tapes, Ltd.

229a. Industrial Wire Brushes
B. O. Morris, Ltd.

230. Instruments (Aero Engine)
Cambridge Instrument Co., Ltd.
Dobbie McInnes, Ltd.
Ferranti, Ltd.
Negretti & Zambra
Sangamo Weston, Ltd.
The British Thermostat Co., Ltd

231. Instruments (Aircraft)
Avimo, Ltd.
Bell Punch Co., Ltd.
Elliott Brothers (London), Ltd.
Evans Electroselenium, Ltd.
Ferranti, Ltd.
A. Kershaw & Sons, Ltd.
Negretti & Zambra
R. B. Pullin & Co., Ltd.
Pye, Ltd.
Sangamo Weston, Ltd.
Short & Mason, Ltd.
Simmonds Aerocessories, Ltd.
The Sperry Gyroscope Co., Ltd.

232. Instruments (Electrical)
The Armature Manufacturing Co.
Automatic Coil Winder & Electrical Equipment Co., Ltd.
Avimo, Ltd.
D. H. Bonnella & Son, Ltd.
Cambridge Instrument Co., Ltd.
Crompton Parkinson, Ltd.
Dobbie McInnes, Ltd.
Elliott Brothers (London), Ltd.
Ether, Ltd.
Evans Electroselenium, Ltd.
Ferranti, Ltd.
Griffin & Tatlock, Ltd.
Ivo Engineering & Construction Co., Ltd.
E. H. Jones (Machine Tools), Ltd.
Londex, Ltd.
Marconi Instruments, Ltd.
Metropolitan-Vickers Electrical Co., Ltd.
Negretti & Zambra
R. B. Pullin & Co., Ltd.
Pye, Ltd.

Rotax, Ltd.
Sangamo Weston, Ltd.
Siemens Electric Lamps & Supplies, Ltd.
The Sperry Gyroscope Co., Ltd.

233. Instruments (Optical)
Avimo, Ltd.
J. E. Baty & Co., Ltd.
Barr & Stroud, Ltd.
Dobbie McInnes, Ltd.
Evans Electroselenium, Ltd.
The Franklin-Carter Co.
Griffin & Tatlock, Ltd.
Adam Hilger, Ltd.
E. H. Jones (Machine Tools), Ltd.
A. Kershaw & Sons, Ltd.
R. B. Pullin & Co., Ltd.
Taylor, Taylor & Hobson, Ltd.
E. R. Watts & Son, Ltd.

234. Instruments (Scientific)
J. E. Baty & Co., Ltd.
Barr & Stroud, Ltd.
Cambridge Instrument Co., Ltd.
The British Thermostat Co., Ltd.
Dobbie McInnes, Ltd.
Elliott Brothers (London), Ltd.
Ether, Ltd.
Griffin & Tatlock, Ltd.
Adam Hilger, Ltd.
E. H. Jones (Machine Tools), Ltd.
A Kershaw & Sons, Ltd.
Negretti & Zambra
R. B. Pullin & Co., Ltd.
Pye, Ltd.
Short & Mason, Ltd.
Taylor, Taylor & Hobson, Ltd.
E. R. Watts & Son, Ltd.

235. Instruments (Testing)
Automatic Coil Winder & Electrical Equipment Co., Ltd.
Avimo, Ltd.
E. P. Barrus, Ltd.
J. E. Baty & Co., Ltd.
Broadway Engineering Co., Ltd
Cambridge Instrument Co., Ltd.
Dobbie McInnes, Ltd.
Elliott Brothers (London), Ltd.
Ether, Ltd.
Ferranti, Ltd.
E. H. Jones (Machine Tools), Ltd.
Marconi Instruments, Ltd.
Monarch Tool Co., Ltd.
Negretti & Zambra
Sangamo Weston, Ltd.
Short & Mason, Ltd.
E. R. Watts & Son, Ltd.
Waymouth Gauges & Instruments, Ltd.

236. Insulating Materials (Electric)
Bitulac, Ltd.
British Belting & Asbestos, Ltd.
J. Burns, Ltd.
The Bushing Co., Ltd.
De La Rue Plastics, Ltd.
Docker Brothers
The Hertfordshire Rubber Co. Ltd.
I.C.I. (Plastics), Ltd.
The Ioco Rubber & Waterproofing Co., Ltd.
The North British Rubber Co., Ltd.
E. Siegrist, Ltd.
Siemens Electric Lamps & Supplies, Ltd.
Tenaplas, Ltd.
Turner Brothers Asbestos Co., Ltd.
United Ebonite & Lorival, Ltd.
Alfred Wiseman & Co., Ltd.

237. Insulating Materials (Heat)
Bitulac, Ltd.
British Belting & Asbestos Ltd.
Expanded Rubber Cos, Ltd.
The Hertfordshire Rubber Co., Ltd.
Turner Brothers Asbestos Co., Ltd.
E. R. Watts & Son, Ltd.

238. Insulating Materials (Sound)
Bitulac, Ltd.
The Hertfordshire Rubber Co., Ltd.
Veneercraft, Ltd.
Wilkinson, Rubber Linatex, Ltd.

239. Jacks (Aircraft)
Automotive Products Co., Ltd.
The Britise Thermostat Co., Ltd.
Harvey Frost & Co., Ltd.
S. Grahame Ross Ltd.
Tangyes, Ltd.

240. Jacks (Lifting)
E. P. Barrus, Ltd.
Henry Berry & Co., Ltd.
T. Chatwin & Co.
Esavian, Ltd.
Guyson Industrial Equipment, Ltd.
Harvey Frost & Co., Ltd.
S. Grahame Ross, Ltd.
Jenks Bros., Ltd.
Tangyes, Ltd.
Walters & Dobson, Ltd.
A. Warden & Co., Ltd.

241. Jigs and Fixtures
A. B.C. Motors, Ltd.
Airwork General Trading Co., Ltd
Arnott & Harrison, Ltd.
Bolton Engineering Co., Ltd.
Broadway Engineering Co., Ltd.
Coventry Gauge & Tool Co., Ltd.
The Coventry Victor Motor Co., Ltd.
Croft Engineering, Ltd.
Dormer & Wadsworth, Ltd.
R. K. Dundas, Ltd.
Earnshaw Bros. & Booth, Ltd.
Gay's (Hampton), Ltd.
Grafton Tools, Ltd.
Hallam, Sleigh & Cheston
Frank Heaver, Ltd.
Hilbert & Whitwam, Ltd.
Leytonstone Jig & Tool Co., Ltd.
Monarch Tool Co., Ltd.
The Norbury Engineering Co., Ltd.
Alfred Partridge & Co., Ltd.
Ratcliffe Tool Co., Ltd.
Rolls Razor, Ltd.
Henry Rossell & Co., Ltd.
B. J. & J. Silcom
Speed Tools, Ltd.
Charles Taylor (Birm.), Ltd.
Tipsy Aircraft Co., Ltd.
Turner Machine Tools, Ltd.
Variform Engineering, Ltd.

242. Jointing Material
Beldam Packing & Rubber Co., Ltd.
Cellon, Ltd.
Docker Brothers
George Angus & Co., Ltd.
J. A. Harrison & Co. (Manchester), Ltd.
The Hertfordshire Rubber Co., Ltd.
I.C.I. (Plastics,) Ltd.
The Ioco Rubber & Waterproofing Co., Ltd.
Harold Jackson, Ltd.
Richard Klinger, Ltd.
The North British Rubber Co., Ltd.
The Patent Motor Product Co.
Simmonds Aerocessories, Ltd.
Slip Products Co., Ltd.
Titanine, Ltd.
Turner Brothers Asbestos Co., Ltd.

243. Joint Rings
Henry Berry & Co., Ltd.
Coopers Mechanical Joints, Ltd.
Delco-Remy & Hyatt, Ltd.
J. A. Harrison & Co. (Manchester), Ltd.
The Hertfordshire Rubber Co., Ltd.
Richard Klinger, Ltd.
Metalastik, Ltd.
The North British Rubber Co., Ltd.
Turner Brothers Asbestos Co., Ltd.

244. Joints (Universal)
J. E. Baty & Co., Ltd.
Hardy Spicer & Co., Ltd.
Metalastik, Ltd.
The Motor Gear & Engineering Co., Ltd.
A. Warden & Co., Ltd.

245. Keys and Cotters
J. E. Baty & Co., Ltd.
W. H. A. Robertson & Co., Ltd.

246. Lacquer
Bitulac, Ltd.
W. Canning & Co., Ltd.
Docker Brothers
Titanine, Ltd.
The Walpamur Co., Ltd.

247. Lapping Machines
James W. Carr & Co., Ltd.
Kitchen & Wade, Ltd.
The Sperry Gyroscope Co., Ltd.

248. Lathes (Bench and Precision)
Broadway Engineering Co., Ltd.
S. T. Coburn & Son, Ltd.
A. Kershaw & Sons, Ltd.
Pultra, Ltd.
Charles Taylor (Birm.), Ltd.

249. Lathes (Boring and Surfacing)
John Cashmore, Ltd.
S. T. Coburn & Son, Ltd.
D. Mitchell & Co., Ltd.
Scottish Machine Tool Corporation, Ltd.

250. Lathes, (Capstan and Turret)
John Cashmore, Ltd.
S. T. Coburn & Son, Ltd.
Pultra, Ltd.
Quick Supply, Ltd.
G. T. Sharp
Charles Taylor (Birm.), Ltd.
H. W. Ward & Co., Ltd.

251. Lathes (Centre)
James W. Carr & Co., Ltd.
John Cashmore, Ltd.
S. T. Coburn & Son, Ltd.
T. S. Harrison & Sons, Ltd.
Alfred Mellor & Sons, Ltd.
D. Mitchell & Co., Ltd.
Pultra, Ltd.
D. & J. Tullis, Ltd.

252. Lathes (Screwcutting)
Broadway Engineering Co., Ltd.
John Cashmore, Ltd.
S. T. Coburn & Son, Ltd.
Coventry Gauge & Tool Co., Ltd.
F. J. Edwards, Ltd.
Alfred Mellor & Sons, Ltd.
D. Mitchell & Co., Ltd.
Scottish Machine Tool Corporation, Ltd.
Charles Taylor (Birm.), Ltd.
D. & J. Tullis, Ltd.

253. Lathes (Semi and Automatic)
Charles Churchill & Co., Ltd.

S. T. Coburn & Son, Ltd.

264. Lathes (Relieving)
David Brown & Sons (Hudd.), Ltd.
John Cashmore, Ltd.

255. Leather
George Angus & Co., Ltd.
Ernest Turner (London), Ltd.

256. Leather Goods (Aircraft)
George Angus & Co., Ltd.
R. A. Blair, Ltd.
L. A. Rumbold & Co., Ltd.
Ernest Turner (London), Ltd.
Weathershields, Ltd.

257. Leather Substitutes
Dufalite, Ltd.
The Ioco Rubber & Waterproofing Co., Ltd.
Ernest Turner (London), Ltd.

258. Lighting Equipment
The Benjamin Electric, Ltd.
D. H. Bonnella & Son, Ltd.
Coventry Climax Engines, Ltd.
Crompton Parkinson, Ltd.
Evans Electroselenium, Ltd.
Midland Electric Manufacturing Co., Ltd.
Rotax, Ltd.
Siemens Electric Lamps & Supplies, Ltd.
Wilmot-Breeden, Ltd.

259. Locating Pins
Aircraft Materials, Ltd.
The Norbury Engineering Co., Ltd.
Presswork Products, Ltd.
Walter Spencer & Co., Ltd.
J. Stead & Co., Ltd.

260. Locating Studs
The Norbury Engineering Co., Ltd.
Walter Spencer & Co., Ltd.

261. Lock Nuts
Morrisons Engineering, Ltd.
A. P. Newall & Co., Ltd.
Charles Richards & Sons
Simmonds Aerocessories, Ltd.
Taylor & Wilson, Ltd.
Weathershields, Ltd.

262. Machined Parts
A.B.C. Motors, Ltd.
Airwork General Trading Co., Ltd.
Bratby & Hinchliffe, Ltd.
T. Chatwin & Co.
The Coventry Victor Motor Co., Ltd.
Dashwood Engineering, Ltd.
R. K. Dundas, Ltd.
Hallam, Sleigh & Cheston
Hedleys, Ltd.
Hellerman Electric, Ltd.
Leytonstone Jig & Tool Co., Ltd.
Chas. S. Madan & Co., Ltd.
Morrisons Engineering, Ltd.
The National Steel Foundry (1914), Ltd.
The Norbury Engineering Co., Ltd.
Ormerod Engineers, Ltd.
Alfred Partridge & Co., Ltd.
Charles Richards & Sons
W. H. A. Robertson & Co., Ltd.
Taylor & Wilson, Ltd.
Tipsy Aircraft Co., Ltd.
The Truform Gauge Co., Ltd.

263. Magnesium
Birmingham Aluminium Casting (1903), Ltd.
Thos. Firth & John Brown, Ltd.
F. A. Hughes & Co., Ltd.
Magnesium Elektron, Ltd.

265. Marking Devices
John H. Elliott
E. H. Jones (Machine Tools), Ltd.
J. Martin & Sons, Ltd.

266. Measuring Instruments (Electrical)
The Armature Manufacturing Co.
Automatic Coil Winder & Electrical Equipment Co., Ltd.
Avimo, Ltd.
Cambridge Instrument Co., Ltd.
Crompton Parkinson, Ltd.
Dobbie McInnes, Ltd.
Elliott Brothers (London), Ltd.
Ferranti, Ltd.
Griffin & Tatlock, Ltd.
Marconi Instruments, Ltd.
Metropolitan-Vickers Electrical Co., Ltd.
R. B. Pullin & Co., Ltd.
Sangamo Weston, Ltd.
Siemens Electric Lamps & Supplies, Ltd.
Taylor, Taylor & Hobson, Ltd.

267. Measuring Instruments (Optical)
Avimo, Ltd.
J. E. Baty & Co., Ltd.
Dobbie McInnes, Ltd.
The Franklin-Carter Co.
Griffin & Tatlock, Ltd.
Adam Hilger, Ltd.
E. H. Jones (Machine Tools), Ltd.
A. Kershaw & Sons, Ltd.
Taylor, Taylor & Hobson, Ltd.

268. Measuring Machines
J. E. Baty & Co., Ltd.
Cambridge Instrument Co., Ltd.
Coventry Gauge & Tool Co., Ltd.
E. H. Jones (Machine Tools), Ltd.
Monarch Tool Co., Ltd.
Pitter Gauge & Precision Tool Co.
E. R. Watts & Son, Ltd.

269. Metal Deposition
W. Canning & Co., Ltd.
R. K. Dundas, Ltd.

269a Metal Spraying
Metallisation, Ltd.

270. Metal Treatment
William Allday & Co., Ltd.
W. Canning & Co., Ltd.
R. K. Dundas, Ltd.
Evans Electroselenium, Ltd.
Macrome, Ltd.
Tipsy Aircraft Co., Ltd.
Titanine, Ltd.
A. H. Wilkes & Co.

271. Micrometers
E. P. Barrus, Ltd.
Charles Churchill & Co., Ltd.
Ambrose Shardlow & Co., Ltd.
Small Tools, Ltd.
Solex, Ltd.

272. Milling Cutters
Edgar Allen & Co., Ltd.
Arnott & Harrison, Ltd.
J. Beardshaw & Son, Ltd.
T. Chatwin & Co.
Clarkson (Engineers), Ltd.
S. T. Coburn & Son, Ltd.
Crolt Engineering, Ltd.
Thos. Firth & John Brown, Ltd.
Frank Heaver, Ltd.
Kendall & Gent (1920), Ltd.
Llewellin's Machine Co., Ltd.
Richard Lloyd & Co., Ltd.
Ratcliffe Tool Co., Ltd.
Henry Rossell & Co., Ltd.
Walter Spencer & Co., Ltd.
Turton Brothers & Matthews, Ltd.
Wm. Ward & Son (Sheffield), Ltd.

273. Milling Machines (Automatic)
Adcock & Shipley, Ltd.
John Cashmore, Ltd.

274. Milling Machines (Hand Lever)
Adcock & Shipley, Ltd.
John Cashmore, Ltd.

275. Milling Machines (Horizontal)
Adcock & Shipley, Ltd.
John Cashmore, Ltd.
S. T. Coburn & Son, Ltd.
F. J. Edwards, Ltd.
A. Kershaw & Sons, Ltd.
J. Parkinson & Son
Tom Senior

276. Milling Machines (Plano)
John Cashmore, Ltd.
Kendall & Gent (1920), Ltd.
Muir Machine Tools, Ltd.

277. Milling Machines (Universal)
Adcock & Shipley, Ltd.
John Cashmore, Ltd.
S. T. Coburn & Son, Ltd.
J. Parkinson & Son

278. Milling Machines (Vertical)
Adcock & Shipley, Ltd
William Asquith, Ltd.
Broadway Engineering Co., Ltd.
John Cashmore, Ltd.
S. T. Coburn & Son, Ltd.
Kendall & Gent (1920), Ltd.
A. Kershaw & Sons, Ltd.
Henry Milnes, Ltd.
Charles Taylor (Birm.), Ltd.

280. Motors (Electric)
The Armature Manufacturing Co.
John Cashmore, Ltd.
Crompton Parkinson, Ltd.
Delco-Remy & Hyatt, Ltd.
Greenwood & Batley, Ltd.
Howells (Electric Motors), Ltd.
Laurence, Scott & Electromotors, Ltd.
McClure & Whitfield
Metropolitan-Vickers Electrical Co., Ltd.
Bruce Peebles & Co., Ltd.
Photowork, Ltd.
R. B. Pullin & Co., Ltd.
Ransomes, Sims & Jefferies, Ltd.
Rotax, Ltd.
The English Electric Co., Ltd.

281. Motors (Geared)
David Brown & Sons (Hudd.), Ltd.
Crompton Parkinson, Ltd.
The English Electric Co., Ltd.
Greenwood & Batley, Ltd.
Photowork, Ltd.

282. Mouldings
D. H. Bonnella & Son, Ltd.
British Tyre & Rubber Co., Ltd.
The Bushing Co., Ltd.
The Hertfordshire Rubber Co., Ltd.
G. Johnson Bros.
James Latham, Ltd.
Plastilume Products, Ltd.
J. Stead & Co., Ltd.
The North British Rubber Co., Ltd.
Wilmot-Breeden, Ltd.

283. Nickel
Aircraft Materials, Ltd.
W. Canning & Co., Ltd.

284. Nibblers
E. P. Barrus, Ltd.
Broom & Wade, Ltd.
S. T. Coburn & Son, Ltd.
F. J. Edwards, Ltd.
Keeton, Sons & Co., Ltd.
A. Kershaw & Sons, Ltd.
The Lakeside Engineering Works

285. Non-ferrous Machine Tools
S. T. Coburn & Son, Ltd.

286. Nut-Runners
The Delta Metal Co., Ltd.
287. Oil Cleaning Machines
British Twin Disc & Clarifiers, Ltd.
J. Glover & Sons, Ltd.
Slip Products Co., Ltd.
Stream-Line Filters, Ltd.
287a. Oil Refuelling Equipment
Thompson Brothers (Bilston), Ltd.
288. Oilers and Lubrication
J. A. Harrison & Co. (Manchester), Ltd.
Slip Products Co., Ltd.
288a. Ovens (Heat Treatment)
Controlled Heat & Air, Ltd.
289. Oxy-Acetylene Equipment
Acetylene Generator & Tool Co., Ltd.
Carbic, Ltd.
Hoggett, Young & Co., Ltd.
Thorn & Hoddle, Ltd.
Tipsy Aircraft Co., Ltd.
A. Warden & Co., Ltd.
291. Oxygen Equipment
Avimo, Ltd.
The Hertfordshire Rubber Co., Ltd.
292. Paint
Bitulac, Ltd.
Cellon, Ltd.
Commercial Structures, Ltd.
Docker Brothers
Northern Aluminium Co., Ltd.
Titanine, Ltd.
Wailes Dove Bitumastic, Ltd.
The Walpamur Co., Ltd.
293. Paint Removers
Bitulac, Ltd.
Cellon, Ltd.
Docker Brothers
Slip Products Co., Ltd.
Titanine, Ltd.
The Walpamur Co., Ltd.
294. Panel Wheeling
F. Corlett & Co., Ltd.
Keeton, Sons & Co., Ltd.
Tipsy Aircraft Co., Ltd.
Westhill Aircraft (Halifax), Ltd.
295a. Petrol Refuelling Equipment
Thompson Brothers (Bilston) Ltd.
295b. Petrol Storage Tanks
Thompson Brothers' (Bilston), Ltd.
295c. Photographic Machinery and Appliances
Lloyds
296. Photostats
Hall Harding, Ltd.
Harper & Tunstall, Ltd.
297. Pipe Cutting and Threading Machines
T. Chatwin & Co.
Kendall & Gent (1920), Ltd.
W. H. A. Robertson & Co., Ltd.
Voucher, Ltd.
298. Piston Rings
The British Piston Ring Co., Ltd.
299. Planing Machines
J. Sagar & Co., Ltd.
Scottish Machine Tool Corporation, Ltd.
John Stirk & Sons, Ltd.
300. Plastics
Bitulac, Ltd.
D. H. Bonnella & Son, Ltd.
British Industrial Plastics, Ltd.
J. Burns, Ltd.
John Dale, Ltd.
De La Rue Plastics, Ltd.
The Hadley Co., Ltd.
Frank Heaver, Ltd.
I.C.I. (Plastics, Ltd.)
M. & B. Plastics, Ltd.
Plastilume Products, Ltd.
Rolls Razor, Ltd.
Saro Laminated Wood Products, Ltd.
J. Stead & Co., Ltd.
Tenaplas, Ltd.
"Triplex" Safety Glass Co., Ltd.
United Ebonite & Lorival, Ltd.
301. Plastics (Laminates)
J. Burns, Ltd.
The Bushing Co., Ltd.
De La Rue Plastics, Ltd.
Expanded Rubber Co., Ltd.
Ferodo, Ltd.
The Ioco Rubber & Waterproofing Co., Ltd.
Merron, Ltd.
M. & B. Plastics, Ltd.
Saro Laminated Wood Products, Ltd.
"Triplex" Safety Glass Co., Ltd
302. Plastics (Transparent Sheet)
The Hadley Co., Ltd.
I.C.I. (Plastics), Ltd.
M. & B. Plastics, Ltd.
Plastilume Products, Ltd.
"Triplex" Safety Glass Co., Ltd.
303. Plating
Avimo, Ltd.
Brailey Electroplaters, Ltd.
W. Canning & Co., Ltd.
Morrisons Engineering Ltd.,
Tipsy Aircraft Co., Ltd.
304. Plugs
D. H. Bonnella & Son, Ltd.
The Hertfordshire Rubber Co., Ltd.
304a. Plugs (Sparking)
Lodge Plugs, Ltd.
305. Plywood
The Aeronautical & Panel Plywood Co., Ltd.
Austin Veneer & Panel Co., Ltd.
James Latham, Ltd.
Merron, Ltd.
The Midland Veneers Service Co.
Saro Laminated Wood Products, Ltd.
306. Pneumatic Tools
Aeraspray Manufacturing Co., Ltd.
E. P. Barrus, Ltd.
J. Beardshaw & Son, Ltd.
Broom & Wade, Ltd.
S. T. Coburn & Son, Ltd.
John Macdonald & Co., (Pneumatic Tools), Ltd.
Samuel Osborn & Co., Ltd.
Henry Rossell & Co., Ltd.
307. Polishing Machines
E. P. Barrus, Ltd.
W. Canning & Co., Ltd.
S. T. Coburn & Son, Ltd.
T. S. Harrison & Sons, Ltd.
Howells (Electric Motors), Ltd.
Henry Milnes, Ltd.
B. O. Morris, Ltd.
Turner Machine Tools, Ltd.
308. Portable Drills and Grinders (Electric)
E. P. Barrus, Ltd.
S. T. Coburn & Son, Ltd.
S. Ralph Golding & Co., Ltd.
B. O. Morris, Ltd.
Morris & Ingram
The New Fortuna Machine Co., Ltd.
S. Wolf & Co., Ltd.
309. Portable Drills and Grinders (Pneumatic)
E. P. Barrus, Ltd.
Broom & Wade, Ltd.
S. T. Coburn & Son, Ltd.
John Macdonald & Co (Pneumatic Tools), Ltd.
310. Portable Electric Tools
E. P. Barrus, Ltd.
S. T. Coburn & Son, Ltd.
B. O. Morris, Ltd.
Morris & Ingram
311. Portable Pneumatic Tools
E. P. Barrus, Ltd.
Broom & Wade, Ltd.
S. T. Coburn & Son, Ltd.
E.M.B. Co., Ltd.
John Macdonald & Co. (Pneumatic Tools), Ltd.
312. Position Indicators
Simmonds Aerocessories, Ltd.
313. Power Plants
A.B.C. Motors, Ltd.
John Cashmore, Ltd.
The Coventry Victor Motor Co., Ltd.
Tangyes, Ltd.
314. Press Tools
Arnott & Harrison, Ltd.
Bolton Engineering Co., Ltd.
Coventry Gauge & Tool Co., Ltd.
Crolt Engineering, Ltd.
Dormer & Wadsworth, Ltd.
Gay's (Hampton), Ltd.
Leytonstone Jig & Tool Co., Ltd.
J. Martin & Sons, Ltd.
Presswork Products, Ltd.
Ratcliffe Tool Co., Ltd.
Henry Rossell & Co., Ltd.
B. J. & J. Silcom
Tipsy Aircraft Co., Ltd.
315. Presses (Arbor)
Henry Berry & Co., Ltd.
S. T. Coburn & Son, Ltd.
F. J. Edwards, Ltd.
Fielding & Platt, Ltd.
The Mortimer Engineering Co.
T. Norton & Co.
316. Presses (Blanking and Forming)
Henry Berry & Co., Ltd.
John Cashmore, Ltd.
S. T. Coburn & Son, Ltd.
Fielding & Platt, Ltd.
Greenwood & Batley, Ltd.
Hordern, Mason & Edwards, Ltd.
T. Norton & Co.
Scottish Machine Tool Corporation, Ltd.
The Sheridan Machinery Co., Ltd.
Walters & Dobson, Ltd.
317. Presses (Drawing)
Henry Berry & Co., Ltd.
Fielding & Platt, Ltd.
Harper & Tunstall, Ltd.
Hordern, Mason & Edwards, Ltd.
318. Presses (Hydraulic)
Henry Berry & Co., Ltd.
Broadway Engineering Co., Ltd.
John Cashmore, Ltd.
Davy & United Engineering Co., Ltd.
Fielding & Platt, Ltd.
Greenwood & Batley, Ltd.
Hopkinsons, Ltd.
Pump Unit, Ltd.
The Hydraulic Engineering Co., Ltd.
Tangyes, Ltd.
Walters & Dobson, Ltd.
Weatherley Oilgear, Ltd.
319. Presses (Hydraulic Extrusion)
Henry Berry & Co., Ltd.
Davy & United Engineering Co., Ltd.
Fielding & Platt, Ltd.

The Hydraulic Engineering Co., Ltd.
Pump Unit, Ltd.
W. H. A. Robertson & Co., Ltd.

320. Presses (Hydraulic Bending, Flanging and Forging)
Henry Berry & Co., Ltd.
John Cashmore, Ltd.
Davy & United Engineering Co., Ltd.
Fielding & Platt, Ltd.
Greenwood & Batley, Ltd.
The Hydraulic Engineering Co., Ltd.
Pump Unit, Ltd.
Tangyes, Ltd.
Weatherley Oilgear, Ltd.

321. Presses (Hydraulic Cupping and Drawing)
Henry Berry & Co., Ltd.
Davy & United Engineering Co., Ltd.
Fielding & Platt, Ltd.
Greenwood & Batley, Ltd.
The Hydraulic Engineering Co., Ltd.
Pump Unit, Ltd.

322. Presses (Hydraulic Scrap Baling)
Henry Berry & Co., Ltd.
Fielding & Platt, Ltd.
Greenwood & Batley, Ltd.
The Hydraulic Engineering Co., Ltd.
Pump Unit, Ltd.

322a. Presses (Mechanical)
Eumuco (England), Ltd.

323. Presses (Moulding Bakelite)
Henry Berry & Co., Ltd.
Broadway Engineering Co., Ltd.
Commercial Structures, Ltd.
E.M.B. Co., Ltd.
Greenwood & Batley, Ltd.
Hordern, Mason & Edwards, Ltd.
The Hydraulic Engineering Co., Ltd.
D. & J. Tullis, Ltd.
Pump Unit, Ltd.

324. Presses (Straightening)
Henry Berry & Co., Ltd.
Joshua Bigwood & Son, Ltd.
Davy & United Engineering Co., Ltd.
E.M.B. Co., Ltd.
Fielding & Platt, Ltd.
Greenwood & Batley, Ltd.
The Hydraulic Engineering Co., Ltd.
Pump Unit, Ltd.
Weatherley Oilgear, Ltd.

325. Presses (Stretch)
Henry Berry & Co., Ltd.
Joshua Bigwood & Son, Ltd.
Fielding & Platt, Ltd.
Greenwood & Batley, Ltd.
The Hydraulic Engineering Co., Ltd.
Pump Unit, Ltd.
W. H. A. Robertson & Co., Ltd.
The Sheridan Machinery Co., Ltd.

327. Profiling Machines
Adcock & Shipley, Ltd.
William Asquith, Ltd.
Broadway Engineering Co., Ltd.
Greenwood & Batley, Ltd.
Kendall & Gent (1920), Ltd.
Muir Machine Tools, Ltd.
J. Sagar & Co., Ltd.
Taylor, Taylor & Hobson, Ltd.

328. Propellor Blades
Airscrew Co., Ltd.
Northern Aluminium Co., Ltd.

329. Propellors
Rotol Airscrews, Ltd.

330. Protective Paints
Cellon, Ltd.
Docker Brothers

331. Pulleys
J. Burns, Ltd.
Douglas, Lawson & Co., Ltd.
J. H. Fenner & Co., Ltd.
Francis W. Harris & Co., Ltd.
Richard Lloyd & Co., Ltd.
United Ebonite & Lorival, Ltd.
A. Warden & Co., Ltd.

332. Pumps (Hydraulic High Pressure)
Automotive Products Co., Ltd.
Bell Punch Co., Ltd.
Henry Berry & Co., Ltd.
Davy & United Engineering Co., Ltd.
Joseph Evans & Sons (Wolverhampton), Ltd.
Fielding & Platt, Ltd.
Greenwood & Batley, Ltd.
Hayward-Tyler & Co., Ltd.
The Hydraulic Engineering Co., Ltd.
Chas. S. Madan & Co., Ltd.
Pneumatic Components, Ltd.
Pump Unit, Ltd.
Tangyes, Ltd.
Towler Brothers (Patents), Ltd.
Weatherley Oilgear, Ltd.

333. Pumps, Rotary
J. H. Ballinger
The Coventry Victor Motor Co., Ltd.
Joseph Evans & Sons (Wolverhampton), Ltd.
Greenwood & Batley, Ltd.
Towler Brothers (Patents), Ltd.
Volspray, Ltd.

334. Pumps (Suds)
David Brown & Sons (Hudd)., Ltd.
T. Chatwin & Co.
S. T. Coburn & Son, Ltd.
Joseph Evans & Sons (Wolverhampton), Ltd.

335. Punching & Shearing Machines
Henry Berry & Co., Ltd.
Joshua Bigwood & Son, Ltd.
John Cashmore, Ltd.
S. T. Coburn & Son, Ltd.
The Coventry Victor Motor Co., Ltd.
Greenwood & Batley, Ltd.
Hedleys, Ltd.
Keeton, Sons & Co., Ltd.
Scottish Machine Tool Corporation, Ltd.
The Wadley Manufacturing Co., Ltd.
Walters & Dobson, Ltd.

336. Pyrometers
The British Rototherm Co., Ltd.
Cambridge Instrument Co., Ltd.
Elliott Brothers (London), Ltd.
Ether, Ltd.
Incandescent Heat Co., Ltd.
Ivo Engineering & Construction, Co., Ltd.
Kasenit, Ltd.
Negretti & Zambra

337. Quenchers
Broadway Engineering Co., Ltd.
Ivo Engineering & Construction Co., Ltd.

337a. Quick Release Pins
Aviation Developments, Ltd.

338. Radiators
British Trane Co., Ltd.
Serck Radiators, Ltd.
Worcester Sheet Metal Co.

339. Reamers
Edgar Allen & Co., Ltd.
E. P. Barrus, Ltd.
J. Beardshaw & Son, Ltd.
David Brown & Sons (Hudd.) Ltd.
James W. Carr & Co., Ltd.
T. Chatwin & Co.
Coventry Gauge & Tool Co., Ltd.
Croft Engineering, Ltd.
Hallam, Sleigh & Cheston
Frank Heaver, Ltd.
Richard Lloyd & Co., Ltd.
Monarch Tool Co., Ltd.
Samuel Osborn & Co., Ltd.
Henry Rossell & Co., Ltd.

340. Refrigeration Equipment
Frank Heaver, Ltd.
Mellor Bromley & Co., Ltd.
Wilmot Breeden, Ltd.

341. Relief Valves
Henry Berry & Co., Ltd.
The British Thermostat Co., Ltd.
Hopkinsons, Ltd.
Pump Unit, Ltd.
The Sperry Gyroscope Co., Ltd.

342. Retraction Mechanism
Automotive Products Co., Ltd.

343. Rivets
Aircraft Materials, Ltd.
Coventry Swaging Co., Ltd.
L. H. Newton & Co., Ltd.
Charles Richards & Sons
Rolls Razor, Ltd.

343a. Riveting (Blind)
Aviation Developments, Ltd

344. Riveters (Hydraulic and Pneumatic)
Aircraft Materials, Ltd.
William Allday & Co., Ltd.
Broadway Engineering Co., Ltd.
Broom & Wade, Ltd.
E.M.B. Co., Ltd.
Fielding & Platt, Ltd.
Greenwood & Batley, Ltd.
Turner Machine Tools, Ltd.
Henry Berry & Co., Ltd.

345. Rolled Thread Bolts
Coventry Swaging Co., Ltd.
A. P. Newall & Co., Ltd.
L. H. Newton & Co., Ltd.
Charles Richards & Sons

346. Rolled Thread Screws
Coventry Swaging Co., Ltd.
A. P. Newall & Co., Ltd.
L. H. Newton & Co., Ltd.

347. Rolled Thread Studs
Coventry Swaging Co., Ltd.
A. P. Newall & Co., Ltd.
L. H. Newton & Co., Ltd.

348. Rollers
F. J. Edwards, Ltd.
W. H. A. Robertson & Co., Ltd.

349. Rolls
Henry Berry & Co., Ltd.
Davy & United Engineering Co., Ltd.
W. H. A. Robertson & Co., Ltd.
Scottish Machine Tool Corporation, Ltd.
The United Steel Companies, Ltd.
The Wadley Manufacturing Co., Ltd.

349a. Rotary Cutters
B. O. Morris, Ltd.

349b. Rotary Files
B. O. Morris, Ltd.

350. Routers
E. P. Barrus, Ltd.
J. Sagar & Co., Ltd.

351. Rubber
British Tyre & Rubber Co., Ltd.
Expanded Rubber Co., Ltd.
The Hertfordshire Rubber Co., Ltd.
Lea Bridge Rubber Works, Ltd.

The North British Rubber Co., Ltd.

352. Rubber-Bonders
Metalastik, Ltd.
The North British Rubber Co., Ltd.
Silentbloc, Ltd.

353. Rubber Products
George Angus & Co., Ltd.
British Tyre & Rubber Co., Ltd.
Expanded Rubber Co., Ltd.
The Hazel Grove Rubber Co., Ltd.
The Hertfordshire Rubber Co., Ltd.
The Ioco Rubber & Waterproofing Co., Ltd.
Lea Bridge Rubber Works, Ltd.
The North British Rubber Co., Ltd.
The Palmer Tyre, Ltd.
United Ebonite & Lorival, Ltd.
Wilkinson Rubber Linatex, Ltd.

354. Rubber (Synthetic)
George Angus & Co., Ltd.
British Tyre & Rubber Co., Ltd.
The Hertfordshire Rubber Co., Ltd.
I.C.I. (Plastics), Ltd.
The North British Rubber Co., Ltd.
The Palmer Tyre, Ltd.
Silentbloc, Ltd.
United Ebonite & Lorival, Ltd.

355. Rudders
Morrisons Engineering, Ltd.
W. H. A. Robertson & Co., Ltd.
Taylor & Wilson, Ltd.
Tipsy Aircraft Co., Ltd.

356. Salt Baths
William Allday & Co., Ltd.
Alldays & Onions, Ltd.
Incandescent Heat Co., Ltd.
Ivo Engineering & Construction Co., Ltd.
Th. Teisen
A. H. Wilkes & Co.

358. Sandblasting Plant
S. T. Coburn & Son, Ltd.
Guyson Industrial Equipment, Ltd.
Spencer & Halstead, Ltd.
Tilghman's Patent Sand Blast Co., Ltd.

359. Sanders
E. P. Barrus, Ltd.
Broom & Wade, Ltd.
S. T. Coburn & Son, Ltd.
John Macdonald & Co. (Pneumatic Tools), Ltd.
The Mortimer Engineering Co.
Turner Machine Tools, Ltd.

360. Sawing and Filing Machines
S. T. Coburn & Son, Ltd.
The Mortimer Engineering Co.
S. Wolf & Co., Ltd.

361. Sawing Machines
Joshua Bigwood & Son, Ltd.
Broadway Engineering Co., Ltd.
S. T. Coburn & Son, Ltd.
Thos. Firth & John Brown, Ltd.
S. Russell & Sons, Ltd.
Charles Taylor (Birm.), Ltd.
Voucher, Ltd.

362. Saws (Band)
Edgar Allen & Co., Ltd.
E. P. Barrus, Ltd.
J. Beardshaw & Son, Ltd.
S. T. Coburn & Son, Ltd.
Thos. Firth & John Brown, Ltd.
Henry Rossell & Co., Ltd.
Spear & Jackson, Ltd.
Wilson Bros. (Leeds), Ltd.

363. Saw (Circular)
Edgar Allen & Co., Ltd.
E. P. Barrus, Ltd.
J. Beardshaw & Son, Ltd.
S. T. Coburn & Son, Ltd.
Thos. Firth & John Brown, Ltd.
Samuel Osborn & Co., Ltd.
S. Russell & Sons, Ltd.
J. Sagar & Co., Ltd.
Spear & Jackson, Ltd.
Wm. Ward & Son (Sheffield), Ltd.
Wilson Bros. (Leeds), Ltd.

364. Saws (Portable)
E. P. Barrus, Ltd.
S. T. Coburn & Son, Ltd.

365. Screw-Drivers (Electric)
E. P. Barrus, Ltd.
S. T. Coburn & Son, Ltd.

366. Screwing Machines
T. Chatwin & Co.
S. T. Coburn & Son, Ltd.
Kendall & Gent (1920), Ltd.
W. H. A. Robertson & Co., Ltd.
Voucher, Ltd.

367. Screws (Socket Head)
S. Ralph Golding & Co., Ltd.
J. W. Naylor & Sons, Ltd.

368. Screws (Thread Cutting)
Pneumatic Components, Ltd.
Yarwood, Ingram & Co., Ltd.

369. Self-Locking Nuts
R. K. Dundas, Ltd.
Morrisons Engineering Ltd.
Simmonds Aerocessories, Ltd.
Taylor & Wilson, Ltd.
Weathershields, Ltd.

369a. Self-Sealing Hose
Wilkinson Rubber Linatex, Ltd.

370. Separators
Edgar Allen & Co., Ltd.
Dewhurst & Partner, Ltd.

372. Shaping Machines
Broadway Engineering Co., Ltd.
F. J. Edwards, Ltd.
Greenwood & Batley, Ltd.
Kitchen & Wade, Ltd.
J. Sagar & Co., Ltd.
The Sheridan Machinery Co., Ltd.
Fredk. Town & Sons

373. Sheet Levelling Equipment
Joshua Bigwood & Son, Ltd.
W. H. A. Robertson & Co., Ltd.

374. Sheet Metal Parts
Airwork General Trading Co., Ltd.
Coopers Mechanical Joints, Ltd.
F. Corlett & Co., Ltd.
Dashwood Engineering, Ltd.
George H. Elt, Ltd.
J. Gardner & Co., Ltd.
Ivo Engineering & Construction Co., Ltd.
G. Johnson Bros.
Morrisons Engineering, Ltd.
Necaco, Ltd.
Presswork Products, Ltd.
Ranalah, Ltd.
Henry Simon, Ltd.
Spencer & Halstead, Ltd.
John Thompson Aero Components, Co.
Tipsy Aircraft Co., Ltd.
Weathershields, Ltd.
Westhill Aircraft (Halifax), Ltd.

375. Sheet Metal Plants
William Allday & Co., Ltd.
John Cashmore, Ltd.
Ivo Engineering & Construction Co., Ltd.
Keeton, Sons & Co. Ltd.
T. Norton & Co.
Ranalah, Ltd.
Scottish Machine Tool Corporation, Ltd.
A. H. Wilkes & Co.

375a. Sheet Oiling Machines
Hedleys, Ltd.

376. Slotting Machines
John Cashmore, Ltd.
Greenwood & Batley, Ltd.
Muir Machine Tools, Ltd.

377. Solders
Multicore Solders, Ltd.
Stanelco Products
Wilbraham & Smith, Ltd.

378. Sound-Proofing
Cellon, Ltd.
L. A. Rumbold & Co., Ltd.

379. Spanners
E. P. Barrus, Ltd.
Hilbert & Whitwam, Ltd.
Jenks Brothers, Ltd.
Morris & Ingram
Charles Richards & Sons
M. Semet & Co., Ltd.
Spear & Jackson, Ltd.
T. Williams' Tilton Road Works, Ltd.

380. Spinning Lathes
Hordern, Mason & Edwards, Ltd.
Charles Taylor (Birm.), Ltd.

381. Spinnings
The Benjamin Electric, Ltd.
G. Johnson Bros.

383. Spray Booths
Aeraspray Manufacturing Co., Ltd.
Aerostyle, Ltd.
W. Canning & Co., Ltd.
J. Gardner & Co., Ltd.
Guyson Industrial Equipment, Ltd.
Ivo Engineering & Construction Co., Ltd.
Geo. W. King, Ltd.
Spencer & Halstead, Ltd.
Volspray, Ltd.

384. Spray Equipment
Aeraspray Manufacturing Co., Ltd.
Aerostyle, Ltd.
W. Canning & Co., Ltd.
Volspray, Ltd.

385. Springs
Thos. Firth & John Brown, Ltd.
Presswork Products, Ltd.
George Salter & Co., Ltd.
J. Stead & Co., Ltd.
Turton Bros. & Matthews, Ltd.

386. Stampings
Coopers Mechanical Joints, Ltd.
Hattersley & Ridge, Ltd.
Light-Metal Forgings, Ltd.
Magnesium Castings & Products, Ltd.
Presswork Products, Ltd.
Charles Richards & Sons
Rotherham Forge & Rolling Mills Co., Ltd.
T. Williams' Tilton Road Works, Ltd.

387. Starters
Avimo, Ltd.
Brookhirst Switchgear, Ltd.
Dewhurst & Partner, Ltd.
Rotax, Ltd.

388. Starters and Switches for Electric Motors
Airedale Electrical & Manufacturing Co., Ltd.
D. H. Bonnella & Son, Ltd.
Brookhirst Switchgear, Ltd.
Crompton Parkinson, Ltd.
Dewhurst & Partner, Ltd.
E.M.B. Co., Ltd.
The English Electric Co., Ltd.
Metropolitan-Vickers Electrical Co., Ltd.
Midland Electric Manufacturing Co., Ltd.

Rotax, Ltd.

389. Steel (Alloy)

Aircraft Materials, Ltd.
Edgar Allen & Co., Ltd.
J. Beardshaw & Son, Ltd.
Brown, Bayley's Steel Works, Ltd.
The Clyde Alloy Steel Co., Ltd.
Colvilles, Ltd.
Darwins, Ltd.
Thos. Firth & John Brown, Ltd.
Joseph Gillott & Sons
Hobson, Houghton & Co., Ltd.
Wm. Jessop & Sons, Ltd.
Arthur Lee & Sons, Ltd.
Nitralloy, Ltd.
Samuel Osborn & Co., Ltd.
Henry Rossell & Co., Ltd.
Rotherham Forge & Rolling Mills Co., Ltd.
J. J. Saville & Co., Ltd.
Walter Spencer & Co., Ltd.
Peter Stubs, Ltd.
The United Steel Companies, Ltd.

390. Steel (Bar)

Aircraft Materials, Ltd.
Edgar Allen & Co., Ltd.
J. Beardshaw & Son, Ltd.
Brown, Bayley's Steel Works, Ltd.
The Clyde Alloy Steel Co., Ltd.
Colvilles, Ltd.
Darwins, Ltd.
Thos. Firth & John Brown, Ltd.
Wm. Jessop & Sons, Ltd.
Arthur Lee & Sons, Ltd.
Samuel Osborn & Co., Ltd.
Henry Rossell & Co., Ltd.
Rotherham Forge & Rolling Mills Co., Ltd.
Hobson, Houghton & Co., Ltd.
J. J. Saville & Co., Ltd.
The United Steel Companies, Ltd.
Wilbraham & Smith, Ltd.

391. Steel Castings

Edgar Allen & Co., Ltd.
Brown, Bayley's Steel Works, Ltd
David Brown & Sons (Hudd.), Ltd.
The Clyde Alloy Steel Co., Ltd.
Darwins, Ltd.
Thos. Firth & John Brown, Ltd.
Hopkinsons Ltd., Huddersfield
Wm. Jessop & Sons, Ltd.
F. H. Lloyd & Co., Ltd.
The National Steel Foundry (1914), Ltd.
Samuel Osborn & Co., Ltd.

392. Steel (Bright Drawn)

The Clyde Alloy Steel Co., Ltd.
Thos. Firth & John Brown, Ltd.
Arthur Lee & Sons, Ltd.
Harold Platt, Ltd.
Charles Richards & Sons
Henry Rossell & Co., Ltd.
J. J. Saville & Co., Ltd.
Peter Stubs, Ltd.
The United Steel Companies, Ltd.
A. Warden & Co., Ltd.

393. Steel (Case-Hardening)

Edgar Allen & Co., Ltd.
Brown, Bayley's Steel Works Ltd.
The Clyde Alloy Steel Co., Ltd.
Colvilles, Ltd.
Darwins, Ltd.
Thos. Firth & John Brown, Ltd.
Hobson, Houghton & Co., Ltd.
Wm. Jessop & Sons, Ltd.
Arthur Lee & Sons, Ltd.
Nitralloy, Ltd.
Samuel Osborn & Co., Ltd.
Henry Rossell & Co., Ltd.
The United Steel Companies, Ltd.

394. Steel (Free Cutting)

The Clyde Alloy Steel Co., Ltd.
Colvilles, Ltd.
Thos. Firth & John Brown, Ltd.
Wm. Jessop & Sons, Ltd.
Arthur Lee & Sons, Ltd.
Samuel Osborn & Co., Ltd.
Charles Richards & Sons
Henry Rossell & Co., Ltd.
J. J. Saville & Co., Ltd.
The United Steel Companies, Ltd.

395. Steel (Sheet)

Edgar Allen & Co., Ltd.
J. Beardshaw & Son, Ltd.
Colvilles, Ltd.
Thos. Firth & John Brown, Ltd
Hobson, Houghton & Co , Ltd.
Wm. Jessop & Sons, Ltd.
Samuel Osborn & Co., Ltd.
Harold Platt, Ltd.
Henry Rossell & Co. Ltd.
Rotherham Forge & Rolling Mills Co., Ltd
Spear & Jackson, Ltd.
The United Steel Companies, Ltd.
Wilbraham & Smith, Ltd.

396. Steel (Stainless)

Edgar Allen & Co., Ltd.
J. Beardshaw & Son, Ltd.
Brown, Bayley's Steel Works, Ltd.
The Clyde Alloy Steel Co., Ltd.
Darwins, Ltd.
Firth-Vickers Stainless Steels, Ltd.
Hobson, Houghton & Co., Ltd.
Wm Jessop & Sons, Ltd.
Arthur Lee & Sons, Ltd.
Samuel Osborn & Co., Ltd.
Henry Rossell & Co., Ltd.
Rotherham Forge & Rolling Mills Co., Ltd.
J. J. Saville & Co., Ltd.
The United Steel Companies, Ltd.
Wilbraham & Smith, Ltd.

397. Steel (Strip)

Hobson, Houghton & Co., Ltd.
Wm. Jessop & Sons, Ltd.
Arthur Lee & Sons, Ltd.
J. B. & S. Lees, Ltd.
Henry Rossell & Co., Ltd.
Rotherham Forge & Rolling Mills Co., Ltd.
The United Steel Companies, Ltd.
Wilbraham & Smith, Ltd.

399. Steel (Wire and Cable)

Arthur Lee & Sons, Ltd.
Martin, Black & Co. (Wire Ropes), Ltd.
The United Steel Companies, Ltd.
Wilbraham & Smith, Ltd.

400. Storage Bins and Racks

The Alliance Foundry Co., Ltd.
A.R.P. Plansafes & Millennium Planfile Co.
J. Burns, Ltd.
John Cashmore, Ltd.
S. T. Coburn & Son, Ltd.
The Fase Manufacturing Co., Ltd.
J. Gardner & Co., Ltd.
J. Glover & Sons, Ltd.
F. W. Potter & Soar, Ltd.
S. Grahame Ross, Ltd.
Weathershields, Ltd.

400a. Straightening Machines (Light Section)

Hedleys, Ltd.

401. Stretching and Forming Machines (Hydraulic)

Henry Berry & Co., Ltd.
Joshua Bigwood & Son, Ltd.
Fielding & Platt, Ltd.
The Hydraulic Engineering Co., Ltd.
Pump Unit, Ltd.
W. H. A. Robertson & Co , Ltd.
Turner Machine Tools, Ltd.
Weatherley Oilgear, Ltd.

402. Switches

Airedale Electrical & Manufacturing Co., Ltd.
Avimo, Ltd.
D. H. Bonnella & Son, Ltd.
The British Thermostat Co., Ltd.
Dewhurst & Partner, Ltd.
Frank Heaver, Ltd.
Metropolitan-Vickers Electrical Co., Ltd.
Midland Electric Manufacturing Co., Ltd.
Pye, Ltd.
Sangamo Weston, Ltd.
Siemens Electric Lamps & Supplies, Ltd.
Waymouth Gauges & Instruments, Ltd.

403. Synthetic Coatings

Cellon, Ltd.
Docker Brothers
E. Siegrist, Ltd.
Titanine, Ltd.
United Ebonite & Lorival, Ltd.
The Walpamur Co., Ltd.

404. Tail Planes

Morrisons Engineering, Ltd.
Necaco, Ltd.
Saro Laminated Wood Products, Ltd.
Tipsy Aircraft Co., Ltd.

405. Tailwheel Units

Automotive Products Co., Ltd.
The Palmer Tyre, Ltd.

406. Tanks

Airwork General Trading Co., Ltd.
John Cashmore, Ltd.
George H. Elt, Ltd.
Merron, Ltd.
Morrisons Engineering, Ltd.
Saro Laminated Wood Products, Ltd.
Worcester Sheet Metal Co.

407. Tapes

E. P. Barrus, Ltd.
The Ioco Rubber & Waterproofing Co., Ltd.
Ernest Turner (London), Ltd.

408. Tappers

The British Aluminium Co., Ltd.
Wearden & Guylee, Ltd.

409. Taps and Dies

Edgar Allen & Co., Ltd.
E. P. Barrus, Ltd.
J. Beardshaw & Son, Ltd.
James W. Carr & Co., Ltd.
T. Chatwin & Co.
Charles Churchill & Co., Ltd.
S. T. Coburn & Son, Ltd.
Croft Engineering, Ltd.
Thos. Firth & John Brown, Ltd.
Richard Lloyd & Co., Ltd.
Samuel Osborn & Co., Ltd.
W. H. A. Robertson & Co., Ltd.
Henry Rossell & Co., Ltd.
Wearden & Guylee, Ltd.

410. Testing Equipment

The Armature Manufacturing Co.
Automatic Coil Winder & Electrical Equipment Co., Ltd.
Avimo, Ltd.
L. J. H. Ballinger
Dobbie McInnes, Ltd.
Elliott Brothers (London), Ltd.
Evans Electroselenium, Ltd.
Griffin & Tatlock, Ltd.
T. S. Harrison & Sons, Ltd.
Chas. S. Madan & Co., Ltd.
Marconi Instruments, Ltd.
Monarch Tool Co., Ltd.

410a. Thermometers
The British Rototherm Co., Ltd.
411. Thinners
Cellon, Ltd.
Docker Bros.
Titanine, Ltd.
412. Thread Milling Machines
John Cashmore, Ltd.
T. Chatwin & Co.
Greenwood & Batley, Ltd.
412a. Timber (Aeronautical)
James Latham, Ltd.
413. Tools
Edgar Allen & Co., Ltd.
E P. Barrus, Ltd.
James W. Carr & Co., Ltd.
Bolton Engineering Co., Ltd.
S. T. Coburn & Son, Ltd.
Croft Engineering, Ltd.
Thos. Firth & John Brown, Ltd.
Hallam, Sleigh & Cheston
Frank Heaver, Ltd.
Hilbert & Whitman, Ltd.
Jenks Brothers, Ltd.
Leytonstone Jig & Tool Co., Ltd.
J. Martin & Sons, Ltd.
Monarch Tool Co., Ltd.
The Mortimer Engineering Co.
Samuel Osborn & Co., Ltd.
Ratcliffe Tool Co., Ltd.
Henry Rossell & Co., Ltd.
The Sheffield Twist Drill & Steel Co., Ltd.
B. J. & J. Silcom
Tipsy Aircraft Co., Ltd.
The Truform Gauge Co., Ltd.
A. H. Wilkes & Co.
414. Tool Bits
Edgar Allen & Co., Ltd.
E. P. Barrus, Ltd.
J. Beardshaw & Son, Ltd.
Broadway Engineering Co., Ltd.
S. T. Coburn & Son, Ltd.
Croft Engineering, Ltd.
Darwins, Ltd.
Thos. Firth & John Brown, Ltd.
Joseph Gillott & Sons
Frank Heaver, Ltd.
Hobson, Houghton & Co , Ltd.
Huddersfield Gauges, Ltd.
Wm. Jessop & Sons, Ltd.
Samuel Osborn & Co., Ltd.
Henry Rossell & Co., Ltd.
J. J. Saville & Co., Ltd.
Walter Spencer & Co., Ltd.
Peter Stubs, Ltd.
Turton Bros. & Matthews, Ltd.
Wm. Ward & Son (Sheffield), Ltd
415. Tool and Die Surface Grinder
S. T. Coburn & Son, Ltd.
J. Martin & Sons, Ltd.
Voucher, Ltd.
417. Tools (Lathe, Shaper, Planer)
Edgar Allen & Co., Ltd.
E. P. Barrus, Ltd.
J. Beardshaw & Son, Ltd.
Broadway Engineering Co., Ltd.
S. T. Coburn & Son, Ltd.
Croft Engineering, Ltd.
Thos. Firth & John Brown, Ltd.
S. Ralph Golding & Co., Ltd.
Wm. Jessop & Sons, Ltd.
Samuel Osborn & Co., Ltd.
The Rennie Tool Co., Ltd.
Henry Rossell & Co., Ltd.
Walter Spencer & Co., Ltd.
Charles Taylor (Birm.), Ltd.
H. W. Ward & Co., Ltd.
417a. Tractors
David Brown (Tractors), Ltd.
418. Tricycle Undercarriages
Automotive Products Co., Ltd.
419. Trolleys
Tyne Truck & Trolley Co., Ltd.
420. Trucks (Industrial)
J. Burns, Ltd.
Crompton Parkinson, Ltd.
Douglas (Kingswood), Ltd.
Greenwood & Batley, Ltd.
R. A. Lister & Co., Ltd.
Ransomes, Sims & Jefferies, Ltd.
Taylor & Wilson, Ltd.
Tyne Truck & Trolley Co., Ltd.
422. Tubing
John Cashmore, Ltd.
G. Johnson Bros.
Northern Aluminium Co., Ltd.
Serck Radiators, Ltd.
Wilkinson Rubber Linatex, Ltd.
423. Tubing (Rubber)
George Angus & Co., Ltd.
British Tyre & Rubber Co., Ltd.
J. A. Harrison & Co. (Manchester), Ltd.
The Hertfordshire Rubber Co., Ltd.
The Ioco Rubber & Waterproofing Co., Ltd
The North British Rubber Co., Ltd.
The Palmer Tyre, Ltd.
E. Siegrist, Ltd.
United Ebonite & Lorival, Ltd.
Wilkinson Rubber Linatex, Ltd.
424. Tubing (Synthetic)
George Angus & Co., Ltd.
British Tyre & Rubber Co., Ltd.
The Bushing Co., Ltd.
The Hertfordshire Rubber Co , Ltd.
The North British Rubber Co., Ltd.
The Palmer Tyre, Ltd.
E. Siegrist, Ltd.
Tenaplas, Ltd.
Wilkinson Rubber Linatex, Ltd.
425. Turned Parts
Airwork General Trading Co., Ltd.
Dashwood Engineering, Ltd.
Leytonstone Jig & Tool Co., Ltd.
The Norbury Engineering Co., Ltd.
Alfred Partridge & Co., Ltd.
Charles Richards & Sons
Taylor & Wilson, Ltd.
426. Turret Lathes
John Cashmore, Ltd.
Charles Taylor (Birm.), Ltd.
H. W. Ward & Co., Ltd.
427. Turrets
The Bristol Aeroplane Co., Ltd.
John Cashmore, Ltd.
Plastilume Products, Ltd.
428. Turret Tooling
Engineering Utilities
Gay's (Hampton), Ltd.
429. Tyre Gauges
Dunlop Rubber Co., Ltd.
Pneumatic Components, Ltd.
A. Schrader's Son
430. Tyres
British Tyre & Rubber Co., Ltd.
Dunlop Rubber Co., Ltd.
Thos. Firth & John Brown, Ltd.
The North British Rubber Co., Ltd.
The Palmer Tyre, Ltd.
431. Undercarriages
Airwork General Trading Co., Ltd.
Automotive Products Co., Ltd.
432. Upholstery
The Ioco Rubber & Waterproofing Co., Ltd.
Lea Bridge Rubber Works, Ltd.
The North British Rubber Co., Ltd.
L. A. Rumbold & Co., Ltd.
Slip Products Co., Ltd.
Ernest Turner (London), Ltd.
Weathershields, Ltd.
433. Vacuum Pumps
Aeraspray Manufacturing Co., Ltd.
Avimo., Ltd.
The Coventry Victor Motor Co., Ltd.
Joseph Evans & Sons (Wolverhampton), Ltd.
Hayward-Tyler & Co., Ltd.
Pneumatic Components, Ltd.
Reavell & Co., Ltd.
Tilghman's Patent Sand Blast Co , Ltd.
Volspray, Ltd.
Whittaker, Hall & Co. (1929). Ltd.
433a. "V" Rope Drives
J. H. Fenner & Co., Ltd.
433b. Valves (Air)
The Wellman Smith Owen Engineering Corporation, Ltd.
434. Valves (Hydraulic)
Henry Berry & Co., Ltd.
The British Thermostat Co., Ltd.
Davy & United Engineering Co., Ltd.
Fielding & Platt, Ltd.
Greenwood & Batley, Ltd.
The Hydraulic Engineering Co., Ltd.
Pump Unit, Ltd.
The Sperry Gyroscope Co., Ltd.
Towler Brothers (Patents), Ltd.
435. Varnish
Cellon, Ltd.
Docker Bros.
Titanine, Ltd.
Wailes Dove Bitumastic, Ltd
The Walpamur Co., Ltd.
436. Veneer
The Ioco Rubber & Waterproofing Co., Ltd.
Merron, Ltd.
The Midland Veneers Service Co.
Saro Laminated Wood Products, Ltd.
437. Vices (Machines and Bench)
Alldays & Onions, Ltd.
James W. Carr & Co., Ltd.
T. Chatwin & Co.
Charles Churchill & Co., Ltd.
S. T. Coburn & Son, Ltd.
Grafton Tools, Ltd.
T. S. Harrison & Sons, Ltd.
Kitchen & Wade, Ltd.
J. Martin & Sons, Ltd.
J. Parkinson & Son
Charles Taylor (Birm.), Ltd.
438. Wax
Slip Products Co., Ltd.
440. Welding
Airwork General Trading Co , Ltd.
Commercial Structures, Ltd.
R. K. Dundas, Ltd.
George H. Elt, Ltd.
J. Gardner & Co., Ltd.
Hoggett, Young & Co., Ltd.
J. Martin & Sons, Ltd.
Morrisons Engineering, Ltd.
Murex Welding Processes, Ltd.
The Quasi-Arc Co., Ltd.
Quick Supply, Ltd.
S. Grahame Ross, Ltd.
Thorn & Hoddle, Ltd.
Tipsy Aircraft Co., Ltd.
441. Welding Machines
S. T. Coburn & Son, Ltd.
Metropolitan-Vickers Electrical Co., Ltd.
Murex Welding Processes, Ltd.
The Quasi-Arc Co., Ltd.

S. Grahame Ross, Ltd.
Thorn & Hoddle, Ltd.

442. Welding Wire or Rod
Carbic, Ltd.
The Delta Metal Co., Ltd
Hoggett, Young & Co., Ltd.
Metropolitan Vickers Electrical Co., Ltd.
Murex Welding Processes, Ltd
J. Stead & Co., Ltd.
Suffolk Iron Foundry (1920), Ltd
Thorn & Hoddle, Ltd
A. Warden & Co., Ltd
Wilbraham & Smith, Ltd.

442a. Welding Electrodes
The Quasi-Arc Co., Ltd.

443. Wheeling
Airwork General Trading Co., Ltd.
F. Corlett & Co., Ltd.
F. J. Edwards, Ltd.
Tipsy Aircraft Co., Ltd.
Westhill Aircraft (Halifax), Ltd

444. Wheels
Douglas, Lawson & Co., Ltd
Dunlop Rubber Co., Ltd
The Palmer Tyre, Ltd.
Tyne Truck & Trolley Co., Ltd

445. Windows
British Tyre & Rubber Co., Ltd
Hallam, Sleigh & Cheston
The Palmer Tyre, Ltd.
Weathershields, Ltd.
Wilmot-Breeden, Ltd.

446. Windscreens
Hallam, Sleigh & Cheston
The Hertfordshire Rubber Co., Ltd
Plastilume Products, Ltd
Slip Products Co., Ltd
Tipsy Aircraft Co., Ltd.
Weathershields, Ltd

447. Wings
Earnshaw Bros & Booth, Ltd
Morrisons Engineering, Ltd
Necaco, Ltd.
Tipsy Aircraft Co., Ltd

448. Wire (Electric)
Frank Heaver, Ltd
Siemens Electric Lamps & Supplies, Ltd

449. Wire Fittings
Thomas Locker & Co., Ltd

450. Wire (Steel)
Arthur Lee & Sons, Ltd.
Penfold Fencing, Ltd.
Charles Richards & Sons
Henry Rossell & Co., Ltd.
Speedwell Wire Co., Ltd
J. Stead & Co., Ltd.
The United Steel Companies, Ltd.
Wilbraham & Smith, Ltd.

451. Wiring Systems
Oddie Fasteners
Siemens Electric Lamps & Supplies, Ltd.

452. Wood-Working Machinery
E. P. Barrus, Ltd
J. Sagar & Co., Ltd
Wilson Bros (Leeds), Ltd

453. X-Ray Equipment
Evans Electroselenium, Ltd.
Adam Hilger, Ltd
Metropolitan Vickers Electrical Co., Ltd
Victor X Ray Corporation, Ltd

454. Zinc
W. Canning & Co., Ltd
Wilbraham & Smith, Ltd

Index of Manufacturers

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A.B.C. Motors, Ltd., Walton-on-Thames, Surrey, (4, 7, 87, 181, 241, 262, 313)

Acetylene Generator & Tool Co., Ltd., Ofrex House, 15-16, Newman Street, London, W.1. (223, 224, 289)

E. G. Acheson, Ltd., 9, Gayfere Street, Westminster, London, S.W.1. (193a)

Acton Bolt & Fine Threads, Ltd., Chase Road, London, N.W. (38)

Adcock & Shipley, Ltd. Ash Street, Leicester. (40, 71, 133, 134, 135, 136, 137, 273, 274, 275, 277, 278, 327)

Aeraspray Manufacturing Co., Ltd., 179-213, Thimble Mill Lane, Birmingham, 7. (7, 10, 87, 219, 223, 224, 306, 383, 384, 433)

The Aeronautical & Panel Plywood Co., Ltd., 218-226, Kingsland Road, London, E.2. (164, 305)

Aero Research, Ltd., Duxford, Cambridge. (193)

Aerostyle, Ltd., 174-176, St. John Street, Clerkenwell, E.C.1. (7, 87, 383, 384)

Aircraft Materials, Ltd., Midland Road, London, N.W.1. (5, 13, 38, 213, 223, 224, 259, 283, 343, 344, 389, 390)

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Airscrew Co., Ltd., Grosvenor Gardens House, Westminster, London, S.W.1. (8, 12, 219, 328)

Airedale Electrical & Manufacturing Co., Ltd., Macta Works, Low Moor, Bradford. (92, 388, 402)

Airwork General Trading Co., Ltd., Westbrook House, 134, Bath Road, Hounslow, Middlesex. (19, 241, 262, 374, 406, 425, 431, 440, 443)

William Allday & Co., Ltd., Alcosa Works, Stourport-on-Severn, Worcestershire. (7, 22, 270, 344, 356, 375)

Alldays & Onions, Ltd., Great Western Works, Small Heath, Birmingham, 11. (175, 212, 356, 137)

Edgar Allen & Co., Ltd., Eyam, Sheffield. (29, 69, 79, 103, 104, 106. 130, 131, 142, 153, 169, 210, 220, 272, 339, 362, 363, 370, 389, 390, 391, 393, 395, 396, 409, 413, 414, 417)

The Alliance Foundry Co., Ltd., Icknield Road, Works, Luton. (47, 63, 65, 66, 67, 68, 400)

Alvis, Ltd., Coventry. (4)

The Anglo Abrasive Works, Ltd., Alperton Lane, Wembley. (1, 116, 207)

George Angus & Co., Ltd., Angus House, Westgate Road, Newcastle-upon-Tyne, 1. (34, 46, 159, 181, 186, 187, 188, 223, 224, 225, 228, 242, 255, 256, 353, 354, 423, 424)

The Armature Manufacturing Co., Middleton Road, Oldham, Lancs. (232, 266, 280, 410)

Arnott & Harrison, Ltd., 22, Hythe Road, Willesden, London, N.W.10. (106, 160, 178, 241, 272, 314)

Automatic Coil Winder & Electrical Equipment Co., Ltd., Winder House, Douglas Street, London, S.W.1. (232, 235, 266, 410)

Automotive Products Co., Ltd., Leamington Spa, (45, 85, 155, 162, 223, 225, 226, 227, 239, 332, 342, 405, 418, 431)

A.R.P. Plansafes & Millennium Planfile Co., 211 Fitzwilliam Street, Sheffield, 1. (129, 400)

William Asquith, Ltd., Highroad Well Works, Halifax. (40, 43, 133, 135, 136, 137, 138, 278, 327)

Austin Veneer & Panel Co., Ltd., Angel Factory Colony, London, N. 18. (305)

Aviation Developments, Ltd., P.O. Box 30, 11-13, Parkway, Welwyn Garden City, Herts. (337a, 348a)

Avimo, Ltd., Taunton, Somerset. (93, 102, 174, 231, 232, 233, 235, 266, 267, 291, 303, 387, 402, 410, 433)

L. J. H. Ballinger, Dudbridge, near Stroud, Glos. (22, 107, 146, 225, 338, 410)

Barr & Stroud, Ltd., 15, Victoria Street, London, S. W.1. (233, 234)

E. P. Barrus, Ltd., Brunel Road, Acton, London, W.3. (11, 40, 72, 83, 130, 135, 143, 153, 178, 194, 200, 210, 213, 235, 240, 271, 284, 306, 307, 308, 309, 310, 311, 339, 350, 359, 362, 363, 364, 365, 379, 407, 409, 413, 414, 417, 452)

J. E. Baty & Co., Ltd., 39, Victoria Street, London, S.W.1. (80, 178, 233, 234, 235, 241, 245, 267, 268)

Charles Baynes, Ltd., Knuzden Brook, Blackburn. (210)

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Beetle Products Co., Ltd., 1, Argyll Street, London, W.1. (70, 193)

Beldam Packing & Rubber Co., Ltd., Windmill Road, Brentford, Middlesex. (242)

Bell Punch Co., Ltd., 39, St. James's Street, London, S.W.1. (90, 226, 231, 332)

Bendix, Ltd., Tyseley, Birmingham, 11. (45)

The Benjamin Electric, Ltd., Brantwood Works, Tariff Road, Tottenham, London, N.17. (258, 381)

Henry Berry & Co., Ltd., Croydon Works, Hunslet, Leeds, 10. (2, 30, 31, 35, 225, 228, 240, 243, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 332, 335, 341, 344, 349, 401, 434)

Joshua Bigwood & Son, Ltd., Wednesfield Road, Wolverhampton. (31, 35, 67, 187, 209, 225, 226, 324, 325, 335, 361, 373, 401)

Birmetals, Ltd., Birmid Works Dartmouth Road, Smethwick, near Birmingham. (14, 15, 16, 17, 18, 169)

Birmingham Aluminium Casting (1903), Co., Ltd., Birmid Works, Smethwick, Birmingham, 40. (14, 63, 64, 68, 263)

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R. A. Blair, Ltd., 66, Chalk Farm Road, London, N. W.1. (256)

Bolton Engineering Co., Ltd., 327, Bury Road, Bolton. (132, 178, 241, 314, 413)

D. H. Bonnella & Son, Ltd, Merriott, Somerset. (5, 56, 92, 93, 112, 176, 224, 232, 258, 282, 300, 304, 388, 402)

Brailey Electroplaters, Ltd., Chapel Street, Salford, 3, Lancs. (19, 303)

Bratoy & Hinchliffe, Ltd., Sandford Street, Cannel Street, Ancoats, Manchester, 4. (113, 155, 262)

The Bristol Aeroplane Co., Ltd., Filton House, Filton, Bristol. (4, 9, 148a, 427)

The British Aluminium Co., Ltd., Oakley Manor, Belle Vue, Shrewsbury, Shropshire. (13, 14, 15, 16, 17, 18, 408)

British Belting & Asbestos, Ltd., Cleckheaton, Yorks. (34, 46, 144a, 236, 237)

British Ermeto Corporation, Ltd., Beacon Works, Hargrave Road, Maidenhead, Berks. (102)

British Furnaces, Ltd., Chesterfield. (175)

British Industrial Plastics, Ltd., 1, Argyll Street, London, W.1. (300)

The British Piston Ring Co., Ltd., Holbrook Lane, Coventry. (66, 298)

The British Rotothern Co., Ltd., Merton Abbey, London, S.W.19. (219, 336, 410a)

The British Thermostat Co., Ltd., Windmill Road, Sunbury-on-Thames, Middlesex. (11, 92, 93, 145, 162, 191, 219, 225, 226, 230, 234, 239, 341, 402, 434)

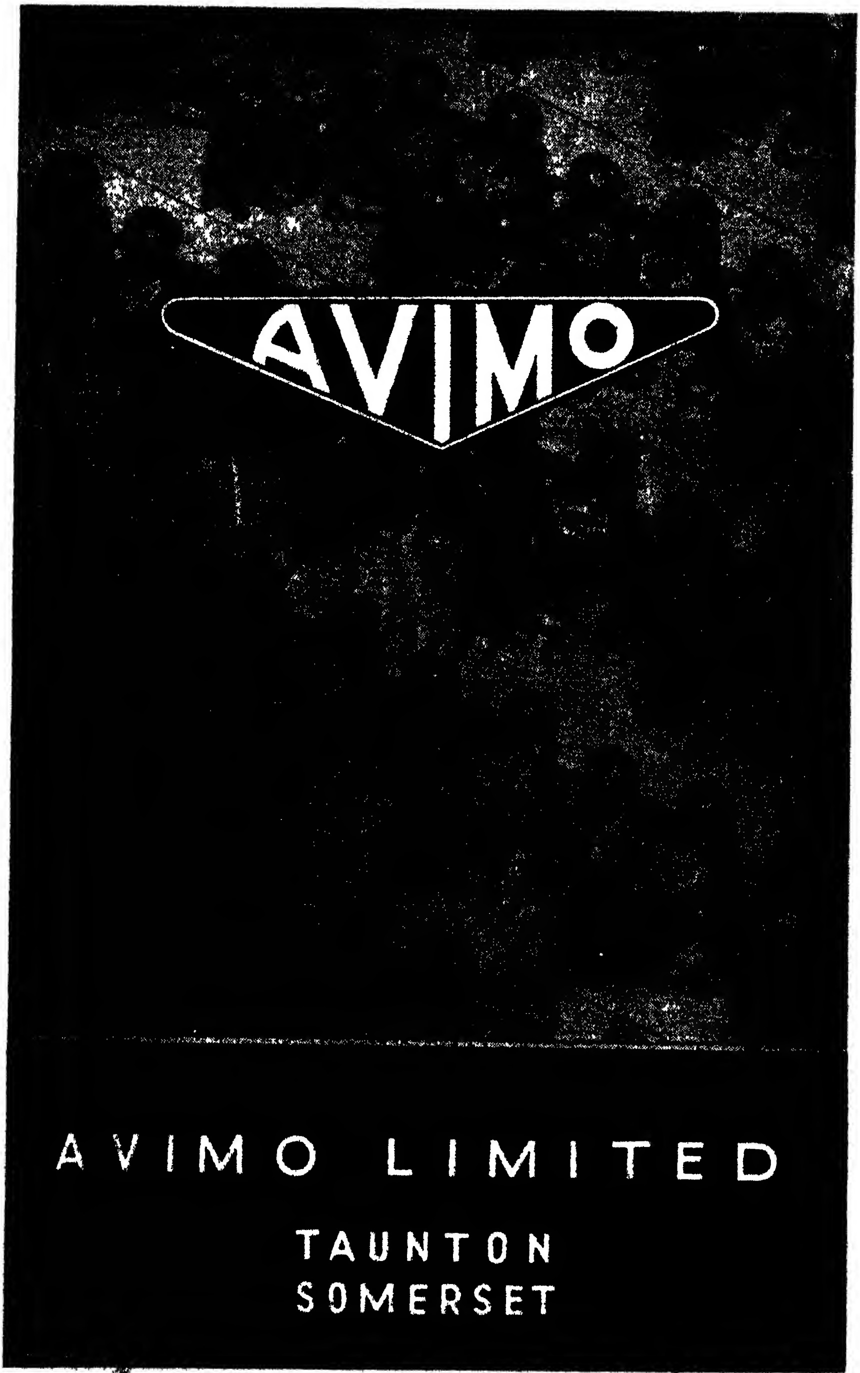
British Timken, Ltd., Cheston Road, Aston, Birmingham, 7. (32)

British Trane Co., Ltd., Vectair House, Clerkenwell Close, London, E.C.1. (8, 218, 219)

British Twin Disc & Clarifiers, Ltd., Aldwych House, Aldwych, London, W.C.2. (74, 85, 156, 287)

British Tyre & Rubber Co., Ltd., Herga House, Vincent Square, London, S.W.1. (20, 33, 34, 177, 228, 282, 351, 353, 354, 423, 424, 430, 445)

Broadway Engineering Co., Ltd., Carlisle Road, Hendon, London, N.W.9. (10, 42, 78, 107, 124, 134, 137, 157, 160, 178, 185, 194, 195, 197, 201, 202, 204, 211, 215, 235, 242, 248, 252, 278, 318, 323, 327, 337, 344, 361, 372, 414, 417)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David Brown & Sons (Hudd.), Ltd., Huddersfield. (68, 69, 105, 181, 182, 184, 185, 186, 187, 188, 189, 205, 251, 281, 334, 339, 391)
David Brown (Tractors), Ltd., Meltham near Huddersfield. (417a)
Brown, Bayley's Steel Works, Ltd., Leeds Road, Sheffield, 9. (69, 169, 220, 389, 390, 391, 393, 396)
J. Burns, Ltd., Wangye Works, Chadwell Heath, Essex. (33, 91, 151, 152, 236, 300, 301, 331, 400, 420)
The Bushing Co., Ltd. Hebburn-on-Tyne (33, 236, 282, 301, 424)
Callender's Cable & Construction, Ltd., Hamilton House, Victoria Embank., London, E.C.4. (57, 140a)
Cambridge Instrument Co., Ltd., 13, Grosvenor Place London, S.W.1. (139, 145, 179, 180, 230, 232, 234, 235, 266, 268, 336)
W. Canning & Co., Ltd., Great Hampton Street Birmingham, 18. (19, 53, 54, 62, 76, 114, 144, 148, 150, 167, 193, 194, 198, 246, 269, 270, 283, 303, 307, 383, 384, 454)
Carbic Ltd., 137, Conway Road, Southgate, N.14. (289, 442)
James W. Carr & Co., Ltd., Northgate House, Moorgate, London, E.C.2. (24, 106, 131, 153, 200, 210, 217, 251, 339, 409, 413, 437)
John Cashmore, Ltd., Eagle Works, Great Bridge, Staffs. (7, 23, 40, 41, 44, 50, 80, 87, 126, 133, 134, 135, 136, 182, 190, 197, 198, 202, 209, 211, 212, 249, 250, 251, 252, 254, 275, 271, 275, 276, 277, 278, 280, 313, 316, 318, 320, 335, 375, 376, 400, 406, 412, 422, 426, 427)
Cellon, Ltd., Kingston-on-Thames. (127, 242, 292, 293, 330, 378, 403, 411, 435)
T. Chatwin & Co., Victoria Works, Great Tindal Street, Birmingham, 16. (83, 106, 130, 131, 153, 211, 240, 262, 272, 297, 331, 339, 366, 409, 412, 437)
Charles Churchill & Co., Ltd., Coventry Road, South Yardley, Birmingham. (24, 106, 131, 134, 153, 207, 210, 213, 253, 271, 409, 437)
Clare-Collets, Ltd., Springfield Lane, Salford, 3. (78, 79, 106)
Clarkson (Engineers), Ltd., George Eliot Garage, Mill Walk, Nuneaton. (78, 272)
The Clyde Alloy Steel Co., Ltd., Craigneuk Works, Motherwell. (69, 169, 172, 220, 389, 390, 391, 392, 393, 394, 396)
S. T. Coburn & Son Ltd., Africa House, Kingsway, W.C.2. (1, 34, 35, 38, 40, 53, 72, 73, 78, 79, 80, 81, 83, 87, 113, 116, 117, 118, 130, 131, 132, 133, 134, 138, 147, 154, 163, 194, 202, 204, 207, 210, 211, 213, 224, 248, 249, 250, 251, 252, 253, 272, 275, 277, 278, 284, 285, 306, 307, 308, 309, 310, 311, 315, 316, 334, 335, 358, 359, 360, 361, 362, 363, 364, 365, 366, 400, 409, 413, 414, 415, 417, 437, 441)
Colvilles, Ltd., 195, West George Street, Glasgow, C.2 (172, 220, 389, 390, 393, 394, 395)
Commercial Structures, Ltd., Staffa Works, Staffa Road, Leyton, E.10. (3, 30, 35, 194, 292, 323, 440)
Connolly Bros. (Curriers), Ltd., Chalton Street, Euston Road, London, N.W.1. (255)
Controlled Heat & Air, Ltd., Cornwall Road, Smethwick, Birmingham. (8, 175, 219, 288a)
Coopers Mechanical Joints, Ltd., 14, Liverpool Road, Slough, Bucks. (21, 101, 151, 155, 177, 243, 374, 386)
Cooper Roller Bearings Co., Ltd., King's Lynn. (32, 85)
F. Corlett & Co., Ltd., Parkside Mill, Edge Lane Street, Royton, near Oldham. (55, 294, 374, 443)
Coventry Climax Engines, Ltd., The Grange, Newbold-on-Stour, Stratford-on-Avon. (159, 258)
Coventry Gauge & Tool Co., Ltd., Fletchamstead, Coventry. (49, 50, 106, 126, 178, 197, 203, 204, 241, 253, 268, 314, 339)
The Coventry Movement Co., Ltd., Spon Street, Coventry. (178)
Coventry Swaging Co. Ltd., Torrington Avenue, Canley, Coventry. (38, 313, 315, 346, 347)
The Coventry Victor Motor Co., Ltd., Coventry, (7, 27, 78, 79, 87, 88, 111, 130, 181, 185, 201, 211, 241, 262, 313, 333, 335, 433)
Croft Engineering, Ltd., Bentinck Street, Bolton. (178, 241, 272, 314, 339, 409, 413, 414, 417)
Crompton Parkinson, Ltd., Electra House, Victoria Embankment, London, W.C.2. (2, 57, 92, 190, 232, 258, 266, 280, 281, 388, 420)
John Dale, Ltd., Brunswick Park Road, New Southgate, London, N.11. (11, 15, 63, 64, 300)
Dartmouth Auto Castings, Ltd., Dartmouth Road, Smethwick, near Birmingham. (66)
Darwins, Ltd., Fitzwilliam Works, Tinsley, Sheffield. (61, 153, 208, 210, 220, 389, 390, 391, 393, 396, 414)
Dashwood Engineering Ltd., Empire Works, Croydon Road Penge, S.E.20. (262, 371, 425)
Davy & United Engineering Co., Ltd., Park Iron Works, Sheffield, 4. (67, 225, 318, 319 320, 321, 324, 332 349, 434)
The De Havilland Aircraft Co., Ltd., Hatfield Aerodrome Herts. (4, 9, 12)
De La Rue Plastics, Ltd., Avenue Works, Walthamstow Avenue, London, E.4. (236, 300, 301)
Delco-Remy & Hyatt, Ltd., Church Street, Dunstable, Beds. (32, 213, 280)
The Delta Metal Co., Ltd., Delta Works, East Greenwich, London, S.E.10 (13, 17, 51, 97, 386, 412)
Dewhurst & Partner, Ltd., Inverness Works, Hounslow. (45, 92, 93, 370, 387, 388, 402)
Die Casting Machine Tools, Ltd., River Works, 122, Green Lanes London, N.13. (64, 121, 122)
Dobbie McInnes, Ltd., 57, Bothwell Street, Glasgow, C.2. (87, 145, 179, 180, 230, 232, 233, 234, 235, 266, 267, 410)
Docker Brothers, 177, Corporation Street, Birmingham, 4. (70, 127, 141, 156, 236, 242, 246, 292, 293, 330, 403, 411, 435)
Dormer & Wadsworth, Ltd., 51-53, Bickersteth Road, Mitcham Road, Tooting, London, S.W.17. (241, 314)
Douglas (Kingswood), Ltd., P.O. Box 1, Kingswood, Bristol. (190, 420)
Douglas, Lawson & Co., Ltd., Birstall, near Leeds. (331, 414)
Dufalite, Ltd., 35, Shenley Road, Boreham Wood, Herts. (192, 257)
R. K. Dundas, Ltd., The Airport, Portsmouth, (22, 30, 90, 114, 160, 178, 241, 262, 269, 270, 369, 440)
Dunlop Rubber Co., Ltd., Fort Dunlop, Erdington, Birmingham, 24. (45, 46, 90, 115, 125, 223, 429, 430, 441)
Dyson & Co., Enfield (1919), Ltd., Southbury Works, Ponders End, Middlesex. (121)
Earnshaw Bros. & Booth, Ltd., Central Mill, Burnley (241, 447)
F. J. Edwards, Ltd., 359-361, Euston Road, London, N.W.1. (35, 137, 197, 209, 211, 252, 275, 284, 315, 348, 372, 413)
Elliott Brothers (London), Ltd., Century Works, Lewisham, London, S.E.13. (145, 166, 231, 232, 234, 235, 266, 336, 410)
Elliott-Lucas, Ltd., 38, Summer Row, Birmingham, 3. (213a)
John H. Elliott, Monostamp Works, Langsett Road, Sheffield, 6. (265)
George H. Elt, Ltd., Eltex Works, Worcester. (3, 11 22, 146, 161, 374, 406, 440)
E.M.B. Co., Ltd., Moor Street, West Bromwich Staffs. (7, 31, 45, 50, 87, 88, 92, 93, 122, 311, 323, 324, 344, 388)
Engineering Utilities, Rosedale Works, Rosedale Road Richmond, Surrey. (428)
The English Electric Co., Ltd., Siemens Works, Stafford. (92, 94, 139, 140, 176, 190, 280, 281, 388)
Esavian, Ltd., Esavian Works, Stevenage, Herts. (22, 240)
Ether, Ltd., Tyburn Road, Erdington, Birmingham, 24. (90, 232, 234, 235, 336)
Eumuco (England), Ltd., Beverley Works, Willow Avenue, Barnes, London, S.W.13. (170 171, 212, 322a)

Joseph Evans & Sons (Wolverhampton), Ltd., Culwell Works, Wolverhampton. (7, 66, 67, 87, 174, 332, 333, 334, 433)

Evans Electroselenium, Ltd., Westminster Bank Chambers, Bishop's Stortford, Herts. (231, 232, 233, 234, 235, 258, 266, 267, 270, 410, 453)

Exactor Control, Ltd., The Cottage, Sterling Works, Dagenham, Essex. (90)

Exide & Drydex Batteries, Grosvenor Gardens House, Grosvenor Gardens, London, S.W.1. (2)

Expanded Rubber Co., Ltd., 675, Mitcham Road, Croydon. (237, 301, 351, 353)

The Fase Manufacturing Co., Ltd., 167, Victoria Street, London, S.W.1. (400)

J. H. Fenner & Co., Ltd., Heckmondwike, Yorks. (34, 85, 223, 331, 433a)

Ferodo, Ltd., Chapel-En-Le Frith, Stockport. (46, 301)

Ferranti, Ltd., Hollinwood, Lancashire. (28, 66, 175, 230, 231, 232, 235, 266)

Fielding & Platt, Ltd., Atlas Works, Gloucester. (30, 31, 225, 228, 315, 316, 317, 318, 319, 320, 321, 322, 324, 325, 332, 344, 401, 431)

Thos. Firth & John Brown, Ltd., Atlas & Norfolk Works, Sheffield, 1. (29, 63, 64, 68, 69, 72, 103, 105, 106, 111, 131, 142, 153, 154, 169, 171, 172, 210, 263, 272, 361, 362, 363, 385, 389, 390, 391, 392, 393, 394, 395, 409, 413, 414, 417, 430)

Firth-Vickers Stainless Steels, Ltd., Staybrite Works, Sheffield, 9. (64, 396)

Fleming, Birkby & Goodall, Ltd., Halifax. (34)

Fletcher Miller, Ltd., Alma Mills, Hyde, Manchester. (62, 108, 114)

Folland Aircraft, Ltd., Hamble, Southampton, Hampshire. (9)

The Franklin Carter Co., Empire House, 159, Gt Charles Street, Birmingham, 3. (233, 267)

J. Gardner & Co., Ltd., New Monument Iron Works, Kent House Lane, Beckenham, Kent. (219, 222, 374, 383, 400, 440)

Gay's (Hampton), Ltd., Oldfield Road, Hampton, Middlesex. (178, 241, 314, 428)

General Fire Appliance Co., Ltd., 11, Waterloo Place, London, S.W.1. (159)

Joseph Gillott & Sons, 14, Priory Road, Sheffield, 7. (389, 414)

F. Gilman (B.S.T.), Ltd., Carlton House, 195 High Street, Smethwick, Staffs. (163, 163a, 163b)

J. Glover & Sons, Ltd., Groton Road, Earlsfield, London, S.W.18. (287, 400)

S. Ralph Golding & Co., Ltd., Orchard House, Penn Road, Beaconsfield, Bucks. (73, 105, 106, 143, 178, 181, 187, 188, 194, 195, 199, 200, 201, 206, 207, 210, 308, 367, 417)

Grafton Tools, Ltd., Broadfields Avenue, Watford By-Pass, Edgware, London. (22, 134, 178, 241, 437)

Graviner Manufacturing Co., Ltd., 16, Bassett Gardens, Osterley, Isleworth, Middlesex. (159)

Greenwood & Batley, Ltd., Albion Works, Leeds. (37, 50, 170, 189, 209, 225, 280, 281, 316, 318, 320, 321, 322, 323, 324, 325, 327, 332, 333, 335, 344, 372, 376, 412, 420, 434)

Griffin & Tatlock, Ltd., Kemble Street, Kingsway, London, W.C.2. (76, 141, 148, 166, 215, 232, 233, 234, 266, 267, 410)

Guyson Industrial Equipment, Ltd., Haddon Place Works, 423, Kirkstall Road, Leeds, 4. (8, 83, 240, 358, 383)

G.W.B. Electric Furnaces, Ltd., Dibdale Works, Dudley. (62, 175)

The Hadley Co., Ltd., Portsmouth Road, Surbiton, Surrey. (300, 302)

Hallam, Sleigh & Cheston, Widney Works, Bagot Street, Birmingham, 4. (78, 79, 106, 160, 213, 241, 262, 339, 413, 445, 446)

David Harcourt, Ltd., Linkula Works, 917-927, Coventry Road, Birmingham, 10. (179, 180)

Hall Harding, Ltd., Stourton House, Dacre Street, Westminster, S.W.1. (128, 129, 296)

Hardinge Machine Tools, Ltd., 104, The Green, Twickenham, Middlesex. (78)

Hardy Spicer & Co., Ltd., Birch Road, Witton, Birmingham, 6. (244)

Harper & Tunstall, Ltd., Leto Works, High Street, Edgware. (128, 129, 296, 317)

Francis W. Harris & Co., Ltd., Burslem, Stoke-on-Trent. (34, 331)

J. A. Harrison & Co. (Manchester), Ltd., Britain Works, London Road, Manchester. (21, 34, 150, 177, 223, 228, 242, 243, 288, 423)

T. S. Harrison & Sons, Ltd., Heckmondwike, England. (73, 134, 165, 194, 195, 199, 251, 307, 410, 437)

Harvey Frost & Co., Ltd., Bishop's Stortford. (239, 240)

Hattersley & Ridge, Ltd., 120, Penistone Road, Sheffield. (169, 386)

The Hazel Grove Rubber Co., Ltd., Bramhall Moor Lane, Hazel Grove, Stockport (353)

Hayward-Tyler & Co., Ltd., Cecil Chambers, 216, Strand, London, W.C.2. (332, 433)

Frank Heaver, Ltd., Kingsley Road, Bideford, North Devon. (49, 72, 105, 106, 140, 241, 272, 300, 339, 340, 402, 413, 414, 448)

Hedleys, Ltd., Forward Works, Bell Street, West Bromwich (35, 37, 134, 136, 137, 262, 335, 375a, 400a)

Heenan & Froude, Ltd., Worcester (139, 146)

Hellermann Electric, Ltd., Gooditric Works, Brewer Street, Oxford. (56, 229, 262)

Hepworth & Grandage, Ltd., St. John's Works, Bradford. (66)

The Hertfordshire Rubber Co., Ltd., Letchworth, Herts. (54, 102, 164, 177, 223, 236, 237, 238, 242, 243, 282, 291, 304, 351, 353, 354, 423, 424, 446)

Herts Pharmaceuticals, Ltd., Welwyn Garden City. (229)

High Duty Alloys, Ltd., 89, Buckingham Avenue, Trading Estate, Slough, Bucks. (13, 14, 15, 16, 17, 18, 63, 64)

Hilbert & Whitwam, Ltd., 92, Warwick Road, Ealing, W.5. (160, 241, 379, 413)

Adam Hilger, Ltd., 98, St. Pancras Way, Camden Road, London, N.W.1. (233, 234, 267, 453)

Hobson, Houghton & Co., Ltd., Don Steel Works, Sheffield, 4. (153, 389, 390, 393, 395, 396, 397, 414)

Hoggett, Young & Co., Ltd., 17, Essex Road, London, N.1. (3, 289, 440, 442)

Hopkinsons, Ltd., Huddersfield. (50, 69, 74, 179, 180, 318, 341, 391)

Hordern, Mason & Edwards, Ltd., Vulcan Works, Pype Hayes, Birmingham, 24. (316, 317, 323, 380)

Howells (Electric Motors), Ltd., York Street, Hanley, Stoke-on-Trent. (54, 194, 280, 307)

Huddersfield Gauges, Ltd., Waterloo, Huddersfield. (178, 414)

F. A. Hughes & Co., Ltd., Abbey House, London, N.W.1. (167, 263)

J. H. Humphreys & Sons, Blackriding Electrical Works, Werneth, Oldham. (81, 115a)

The Hydraulic Engineering Co., Ltd., Chester. (31, 35, 225, 318, 319, 320, 321, 322, 323, 324, 325, 332, 401, 434)

I.C.I. Metals, Ltd., Birmingham (13, 14, 15, 16, 17, 18, 47, 96, 97, 98, 99, 100)

I.C.I. (Plastics), Ltd., Welwyn Garden City, Herts. (70, 236, 242, 300, 302, 354)

Incandescent Heat Co., Ltd., Cornwall Road, Smethwick, Birmingham. (175, 336, 356)

Industrial Tapes, Ltd., 52, Margaret Street, London, W.1. (3a, 229)

The Ioco Rubber & Waterproofing Co., Ltd., Netherton Works, Anniesland, Glasgow, W.3. (223, 236, 242, 257, 301, 353, 407, 423, 432, 436)

Ivo Engineering & Construction Co., Ltd., Wood Lane, London, W.12. (92, 113, 175, 219, 222, 232, 336, 337, 356, 374, 375, 383)

Geo. Jackman Machine Tool Co., Ltd., 202, Green Lanes, Palmers Green, N.13. (198)

Harold Jackson, Ltd., The Oakenclough Paper Mills, Garstang, near Preston. (177, 242)

Jenks Brothers, Ltd., Britool Works, Bushbury, Wolverhampton. (213, 240, 379, 413)

Wm. Jessop & Sons, Ltd., Brightside Works, Sheffield. (69, 103, 111, 142, 172, 389, 390, 391, 393, 394, 395, 396, 397, 414, 417)

G. Johnson Bros., 103-149, Cornwall Road, South Tottenham, N.15. (30, 55, 218, 282, 374, 381, 422)
E. H. Jones (Machine Tools), Ltd., Edgware Road, The Hyde, London, N.W.9. (40, 178, 189, 197, 232, 233, 234, 235, 265, 267, 268)
Kasenit, Ltd., 7, Holyrood Street, Bermondsey Street, London, S.E.1. (61, 62, 175, 336)
H. W. Kearns & Co., Ltd., Broadheath, near Manchester. (40, 41, 43)
Keeton, Sons & Co., Ltd., Royds Foundry & Engineering Works, Royds Lane, Attercliffe, Sheffield, 4. (35, 208, 209, 284, 294, 335, 375)
Kendall & Gent (1920), Ltd., Victoria Works, Gorton, Manchester. (50, 106, 204, 272, 276, 278, 297, 327, 366)
Kent Alloys, Ltd., Commercial Road, Strood, Kent. (63, 64, 68, 121)
A. Kershaw & Sons, Ltd., Harehills Lane, Leeds, 8. (95, 134, 136, 231, 233, 234, 248, 267, 275, 278, 284)
Geo. W. King, Ltd., Hartford Works, Hitchin, Herts. (22, 93a, 214, 383)
Kitchen & Wade, Ltd., Arundel Street, Halifax. (40, 41, 43, 71, 130, 133, 135, 136, 137, 138, 221, 247, 372, 437)
Kleen-e-ze Brush Co., Ltd., Hanham, Bristol. (53)
Richard Klinger, Ltd., Klingerit Works, Sidcup, Kent. (177, 242, 243)
Lactocol, Ltd., Walton-on-the-Hill, Tadworth, Surrey. (193)
The Lakeside Engineering Works, Wokingham, Berks. (284)
James Latham, Ltd., Leeside Wharf, Mount Pleasant Hill, E.5. (151, 282, 305, 412a)
Laurence, Scott & Electromotors, Ltd., Norwich. (139, 146, 190, 280)
Laystall Engineering Co., Ltd., 53, Great Suffolk Street, London, S.E.1. (3, 111)
Lea Bridge Rubber Works, Ltd., Priory Works, Arterial Road, Southend-on-Sea. (70, 109, 125, 351, 353, 432)
Arthur Lee & Sons, Ltd., Crown Steel & Wire Mills, Bessemer Road, Sheffield, 9. (389, 390, 392, 393, 394, 396, 397, 399, 450)
J. B. & S. Lees, Ltd., Albion Strip Mills, West Bromwich. (397)
Leytonstone Jig & Tool Co., Ltd., 606, High Road, Leyton, London, E.10. (160, 213, 241, 262, 314, 413, 425)
Light-Metal Forgings, Ltd., Churchbridge, Oldbury, near Birmingham. (14, 169, 386)
R. A. Lister & Co., Ltd., Dursley, Gloucester. (420)
Llewellin's Machine Co., Ltd., King Square, Bristol, 2. (72, 106, 130, 181, 185, 186, 187, 188, 189, 272)
F. H. Lloyd & Co., Ltd., James Bridge Steel Works, near Wednesbury. (69, 391)
Richard Lloyd & Co., Ltd., Steelhouse Works, Oliver Street, Birmingham, 7. (1, 34, 106, 207, 272, 331, 339, 409)
Lloyds, 72, Bridge Street, Christchurch, Hants. (295c)
Thomas Locker & Co., Ltd., Church Street, Warrington. (449)
Lodge Plugs, Ltd., Rugby. (216, 304a)
Londex, Ltd., Anerley Works, 207, Anerley Road, London, S.E.20. (92, 93, 232)
John Macdonald & Co. (Pneumatic Tools), Ltd., 175, Shawbridge Street, Pollokshaws, Glasgow, S.3. (212, 306, 309, 311, 359)
Macrome, Ltd., Alcester, Warwickshire. (270)
Chas. S. Madan & Co., Ltd., Vortex Works, Broadheath, Altrincham. (65, 68, 73, 262, 332, 410)
Magnesium Castings & Products, Ltd., Slough. Bucks. (68, 86, 121, 169, 386)
Magnesium Elektron, Ltd., Abbey House, London, N.W.1. (263)
Marconi Instruments, Ltd., Electra House, Kingsway, London, W.C.2. (232, 235, 266, 410)
Marconi's Wireless Telegraph Co., Ltd., Electra House, Victoria Embankment, London, W.C.2. (216)
Martin, Black & Co. (Wire Ropes), Ltd., Speedwell Works, Coatbridge, near Glasgow, Scotland. (57, 399)
J. Martin & Sons, Ltd., Park Street, Higher Ardwick, Manchester, 12. (178, 213, 265, 314, 413, 415, 437, 440)
McClure & Whitfield, Mersey Dynamo Works, Range Road, Adswood, Stockport. (280)
Meigh High Tensile Alloys, Ltd., Sunningend Works, Cheltenham. (68)
Alfred Mellor & Sons, Ltd., Moldgreen Engineering Works, (Carr Pit Road, Moldgreen), Huddersfield. (251, 252)
Mellor Bromley & Co., Ltd., Minotaur Works, St. Saviours Road East, Leicester. (8, 74, 219, 340)
Merron, Ltd., Simplex Works, 181, Bow Road, London, E.3. (125, 301, 305, 406, 436)
Metalastik, Ltd., Evington Valley Road, Leicester. (20, 102, 243, 244, 352)
Metallisation, Ltd., Peartree Lane, Dudley. (13a, 269a)
Metropolitan-Vickers Electrical Co., Ltd., Trafford Park, Manchester, 17. (92, 93, 190, 232, 266, 280, 388, 402, 441, 442, 453)
The M.G. Car Co., Ltd., Abingdon-on-Thames. (3)
Midland Electric Manufacturing Co., Ltd., Reddings Lane, Tyseley, Birmingham, 11. (92, 176a, 258, 388, 402)
The Midland Veneers Service Co., Butler Street, Small Heath, Birmingham, 10. (305, 436)
Henry Milnes, Ltd., Machine Tool Works, Ingleby Street, Bradford, Yorks. (154, 278, 307)
D. Mitchell & Co., Ltd., Central Iron Works, Parson Street, Keighley. (135, 249, 251, 252)
Monarch Tool Co., Ltd., Kirkheaton, Huddersfield. (22, 160, 178, 235, 241, 268, 339, 410, 413)
B. O. Morris, Ltd., Tythe Barn Lane, Shirley, Birmingham. (106, 143, 150, 153, 154, 163, 163a, 163c, 213, 229a, 307, 308, 310, 349a, 349b)
Morris & Ingram, 36-38 New Broad Street, London, E.C.2. (210, 221, 308, 310, 379)
Morrisons Engineering, Ltd., Purley Way, Croydon. (5, 6, 9, 11, 19, 38, 158, 161, 164, 261, 262, 303, 355, 369, 374, 404, 406, 440, 447)
The Morse Chain Co., Ltd. Works Road, Letchworth, Herts. (75, 102)
The Mortimer Engineering Co., Acton Lane, London, N.W.10. (40, 49, 54, 134, 136, 137, 154, 194, 315, 359, 360, 413)
The Motor Gear & Engineering Co., Ltd., Essex Works, Chadwell Heath, Essex. (181, 186, 187, 188, 189, 241)
Muir Machine Tools, Ltd., Sherborne Street, Britannia Works, Manchester, 3. (28, 41, 184, 187, 276, 327, 376)
Multicore Solders, Ltd., Bush House, London, W.C.2. (377)
Murex Welding Processes, Ltd., Waltham Cross, Herts. (440, 441, 442)
The National Steel Foundry (1914), Ltd., Leven, Fife. (61, 63, 69, 142, 262, 391)
J. W. Naylor & Sons, Ltd, Albert Street, Oldbury, Birmingham. (367)
Necaco, Ltd., P.O. Box 4, Caernarvon, N. Wales. (19, 374, 401, 447)
Negretti & Zambra, 122, Regent Street, London, W.1. (145, 179, 230, 231, 232, 234, 235, 336)
A. P. Newall & Co., Ltd., Woodside Engineering Works, Possilpark, Glasgow, N. (38, 261, 345, 346, 347)
The New Fortuna Machine Co., Ltd., Fortuna Works, Southmead, Bristol. (29, 147, 210, 211, 308)
New Hudson, Ltd., Garrison Lane, Birmingham, 9. (45)
L. H. Newton & Co., Ltd, Nechells, Birmingham, 7. (27, 38, 343, 345, 346, 347)
Nitralloy, Ltd., 25, Taptonville Road, Sheffield, 10. (389, 393)
The Norbury Engineering Co., Ltd., Great Norbury Street, Hyde, Cheshire. (132, 160, 178, 241, 259, 260, 262, 425)
The North British Rubber Co., Ltd., 204-208, Tottenham Court Road, London, W.1. (20, 34, 54, 177, 223, 236, 242, 243, 282, 351, 352, 353, 354, 423, 424, 430, 432)
Northern Aluminium Co., Ltd., Banbury, Oxon. (12, 14, 15, 16, 17, 18, 64, 68, 121, 169, 292, 328, 422)
T. Norton & Co., 92-93, Carver Street, Birmingham, 1. (315, 316, 375)
Norton Grinding Wheel Co., Ltd., Welwyn Garden City, Herts. (1, 207)

Oddie Fasteners, "Plaza Hall" Portswood Road, Southampton. (110, 125, 451)
Ormerod Engineers, Ltd., Hollows Works, 54-56, Shawclough Road, Rochdale. (262)
Samuel Osborn & Co., Ltd., Clyde Steel Works, Sheffield, 3. P.O. Box 1. (69, 72, 73, 103, 104, 106, 130, 131, 153, 169, 172, 210, 213, 220, 306, 339, 363, 389, 390, 391, 393, 394, 395, 396, 409, 413, 414, 417)
Ozalid Co., Ltd., 7, Birchin Lane, E.C.3. (129)
The Palmer Tyre, Ltd., Herga House, Vincent Square, London, S.W.1. (45, 90, 223, 226, 353, 354, 405, 423, 424, 430, 444, 445)
The G.Q. Parachute Co., Ltd., Stadium Works, Woking, Surrey. (11)
Parkinson & Son, Shipley, Yorks. (105, 126, 182, 183, 275, 277, 437)
Alfred Partridge & Co., Ltd., Ashton Road, Bredbury, Stockport. (160, 241, 262, 425)
The Patent Motor Product Co., 160, New Cavendish Street, Gt Portland Street, London, W.1 (242)
Bruce Peebles & Co., Ltd., Edinburgh, 5. (190, 280)
Penfold Fencing, Ltd., Watford. (34, 150)
Phillips & Powis Aircraft, Ltd., The Aerodrome, Berkshire. (9)
Photowork, Ltd., 10, Briggate, Leeds. (190, 280, 281)
The Pilot Plug Gauge Co., Ltd., 9, Warwick Avenue, Coventry. (178)
Pitter Gauge & Precision Tool Co., Acme Works, Kingston Road, Leatherhead, Surrey. (178, 268)
M. & B. Plastics, Ltd., Dagenham, Essex. (5, 152, 300, 301, 302)
Plastilume Products, Ltd., Station Works, High Wycombe, Bucks. (222, 282, 300, 302, 427, 446)
Harold Platt, Ltd., Albion Strip Mills, West Bromwich. (392, 395)
J. W. & H. Platt, Ltd., Byron Works, Bouverie Road, Harrow, Middlesex. (210)
Pneumatic Components, Ltd., John Street, Sheffield, 2. (7, 11, 27, 66, 87, 88, 155, 179, 228, 332, 368, 429, 433)
F. W. Potter & Soar, Ltd., Phipp Street, London, E.C.2. (400)
Presswork Products, Ltd., Park Royal Road, London, N.W.10. (110, 259, 314, 374, 385, 386)
R. B. Pullin & Co., Ltd., Phoenix Works, Great West Road, Brentford, Middlesex. (92, 178, 231, 232, 233, 234, 266, 280)
Pultra, Ltd., 24, Gravel Lane, Salford, 3, Manchester. (73, 78, 206, 248, 250, 251)
Pump Unit, Ltd., 25, Coptic Street, London, W.C.1. (225, 227, 318, 319, 320, 321, 322, 323, 324, 325, 332, 341, 401, 434)
Pye, Ltd., Radio Works, Cambridge. (231, 232, 234, 402)
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Quick Supply, Ltd., 75, Coleshill Street, Birmingham, 4. (169, 250, 440)
Ranalah, Ltd.. Ranalah Works, Morden Road, Merton, S.W.19. (374, 375)
Ransome & Marles Bearing Co., Ltd., Newark-on-Trent. (32)
Ransomes, Sims & Jefferies, Ltd., Orwell Works, Ipswich. (280, 420)
Ratcliffe Tool Co., Ltd., Gorst Road, Park Royal, London, N.W 10. (22, 106, 178, 241, 272, 314, 413)
Reavell & Co., Ltd., Ranelagh Works, Ipswich. (7, 87, 88, 433)
The Rennie Tool Co., Ltd., Barton Works, 227, Upper Brook Street, Manchester, 13. (103, 417)
Charles Richards & Sons, Imperial Works, Darlaston. (27, 38, 169, 172, 261, 262, 343, 345, 379, 386, 392, 394, 425, 450)
W. H. A. Robertson & Co., Ltd., Lynton Works, Bedford (31, 47, 51, 63, 65, 68, 171, 209, 245, 262, 297, 319, 325, 348, 349, 355, 360, 373, 401, 409)
Rolls Razor, Ltd., Cricklewood Broadway, N.W.2. (5, 27, 90, 241, 300, 343)
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S Grahame Ross, Ltd., Bath Road, Slough. (22, 214, 225, 239, 240, 400, 440, 441)
Henry Rossell & Co., Ltd., Waverley Works, Sheffield. (29, 44, 72, 73, 105, 106, 130, 131, 132, 153, 169, 172, 208, 210, 213, 241, 272, 306, 314, 339, 362, 389, 390, 392, 393, 394, 395, 396, 397, 409, 413, 414, 417, 450)
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Rotax, Ltd., Rotax Works, Willesden Junction, London, N.W.10. (2, 57, 92, 93, 115, 174, 190, 216, 232, 258, 280, 387, 388)
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Rotol Airscrews, Ltd., Cheltenham Road, Gloucester. (329)
L. A. Rumbold & Co., Ltd., Kingsgate Place, Kilburn, London, N.W.6. (55, 109, 217, 222, 256, 378, 432)
S. Russell & Sons, Ltd., Bath Lane, Leicester (65, 66, 67, 68, 361, 363)
J Sagar & Co., Ltd., Canal Works, Halifax. (29, 107, 131, 299, 327, 350 363, 372, 452)
George Salter & Co., Ltd., 10, Lime Street, London, E.C.3. (32, 66 139, 179, 180, 385)
Sangamo Weston, Ltd., Great Cambridge Road, Enfield, Middlesex. (145, 230, 231, 232, 235, 266, 402)
Sankey Sheldon, Stroud Court, Eynsham, near Oxford. (149a)
Saro Laminated Wood Products, Ltd., Folly Works, Whippingham, East Cowes, Isle of Wight. (125, 300, 301, 305, 404, 406, 436)
J. J. Saville & Co., Ltd., Triumph Steel Works, Sheffield, 1. (103, 112, 153, 172, 389, 390, 392, 394, 396, 414)
M. Semet & Co., Ltd., 2, Caxton Street, Westminster, S.W.1. (213, 379)
Tom Senior, Atlas Works, Liversedge, Yorks. (126, 147, 198, 275)
Ambrose Shardlow & Co., Ltd., Ealing Works, P.O. Box 128, Meadow Hall, Sheffield. (111, 271)
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A. Schrader's Son, 829, Tyburn Road, Erdington, Birmingham, 24 (11, 102, 179, 429)
Scottish Machine Tool Corporation, Ltd., 124, St. Vincent Street, Glasgow, C.2. (30, 31, 35, 40 41, 249, 252, 299, 316, 335, 349, 375)
Serck Radiators, Ltd, Warwick Road, Birmingham, 11. (17, 55, 95, 175, 218, 219, 338, 422)
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The Sheridan Machinery Co., Ltd., 74, High Street, Rickmansworth, Herts (177a, 316, 325, 372)
Short Brothers (Rochester & Bedford), Ltd., Seaplane Works, Rochester, Kent. (9, 68, 168)
Short & Mason, Ltd., Aneroid Works, Macdonald Road, Walthamstow, London, E.17. (145, 166, 179, 180, 231, 234, 235)
E. Siegrist, Ltd., 39, Berners Street, London, W.1. (56, 236, 403, 423, 424)
Siemens Electric Lamps & Supplies, Ltd., 38-39, Upper Thames Street, London, E.C.4. (57, 94, 232, 236, 258, 266, 402, 448, 451)
B. J. & J. Silcom, Bury Road, Bolton. (132, 178, 241, 314, 413)
Silentbloc, Ltd., Victoria Gardens, Ladbroke Road, Notting Hill Gate, London, W.11. (20, 33, 102, 352, 354)
Simmonds Aerocessories, Ltd., Great West Road, Brentford, London. (38, 90, 110, 164, 173, 178, 231, 242, 261, 312, 369)
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Slip Products Co., Ltd., Ling House, Dominion Street, London, E.C.2. (34, 58, 70, 108, 113, 114, 242, 287, 288, 293, 432, 438, 446)
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Walter Spencer & Co., Ltd., Crescent Steel Works, Warren Street, Sheffield, 4. (49, 105, 106, 131, 153, 169, 220, 259, 260, 272, 389, 414, 417)
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The Sperry Gyroscope Co., Ltd., Great West Road, Brentford, London. (20, 28, 180, 226, 227, 231, 232, 247, 341, 431)
The Standard Motor Co., Ltd., Canley, Coventry. (4, 9)
Stanelco Products, Ferndown, Northwood Hills, Middlesex. (377)
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John Stirk & Sons, Ltd., Ovenden Road, Halifax. (299)
James Stott & Co. (Engineers), Ltd., Vernon Works, Oldham. (58, 94)
Stream-Line Filters, Ltd., Ingate Place, London, S.W.8. (155, 287)
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Suffolk Iron Foundry (1920), Ltd., Sifbronze Works, Stowmarket. (3, 66, 112)
Talbot Tool Co., Ltd., 87, Borough High Street, S.E.1. (132)
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Charles Taylor (Birm.), Ltd., Bartholomew Street, Birmingham, 5. (30, 35, 48, 78, 79, 80, 107, 241, 248, 250, 252, 278, 361, 380, 417, 426, 437)
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Taylor, Taylor & Hobson Ltd., 137, The Broadway, Mill Hill, London, N.W.7. (124, 126, 147, 148, 233, 234, 266, 267, 327)
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Tilghman's Patent Sand Blast Co., Ltd., Broadheath, near Manchester. (7, 87, 358, 433)
Tipsy Aircraft Co., Ltd., 20, Elmwood Avenue, Feltham, Middlesex. (3, 6, 9, 30, 109, 158, 161, 222, 241, 262, 270, 289, 294, 303, 314, 355, 374, 404, 413, 440, 443, 446, 447)
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The Truform Gauge Co., Ltd., 58, Villa Road, Handsworth, Birmingham, 19. (178, 262, 413)
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Ernest Turner (London), Ltd., Northdown House, Northdown Street, King's Cross, London, N.1. (59, 60, 70, 84, 109, 149, 150, 164, 193, 222, 255, 256, 257, 407, 432)
Turner Machine Tools, Ltd., 63-68, Princip Street, Birmingham, 4. (1, 18, 71, 165, 178, 196, 198, 202, 241, 307, 344, 359, 401)
Turton Brothers & Matthews, Ltd., Wentworth Street, P.O. Box 40, Sheffield. (131, 208, 272, 385, 414)
Tyne Truck & Trolley Co., Ltd., 66-68, Northumberland Street, Newcastle-upon-Tyne, 1. (119, 420, 444)
United Ebonite & Lorival, Ltd., Springside Works, Little Lever, near Bolton, Lancs. (236, 300, 331, 353, 354, 423, 424)
The United Steel Co's., Ltd., Sheffield. (67, 169, 172, 220, 349, 389, 390, 392, 393, 394, 395, 396, 397, 399, 450)
S. L. Van Moppes, St. Andrews House, 32-34, Holborn Viaduct, London, E.C.1. (116, 117, 118, 119, 120)
Variform Engineering, Ltd., Acme Works, 49, Kingston Road, Leatherhead, Surrey. (241)
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Wilmot Breeden, Ltd., Eastern Works, Camden Street, Birmingham, 1. (121, 258, 282, 340, 445)
Wilson Bros. (Leeds), Ltd., Victoria Road, Leeds, 11. (29, 362, 363, 452)
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